THE

YOUNG MILL-WRIGHT

AND

MILLER'S GUIDE.

IN FIVE PARTS.

CONTAINING:—

PART I.—Mechanics and Hydraulics; showing Errors in the OLD, and establishing a NEW System of Theories of Water-Mills, by which the power of Mill-Seats, and the effects they will produce, may be ascertained by calculation.

PART II.—Rules for applying the Theories to practice; Tables for proportioning Mills to the power and fall of the Water, and Rules for finding Pitch Circles, with Tables from 6 to 136 cogs.

PART III.—Directions for constructing and using all the Author's patented Improvements in Mills.

PART IV.—The Art of manufacturing Meal and Flour in all its parts, as practised by the most skilful Millers in America.

PART V.—The Practical Mill-Wright; containing instructions for building Mills, with Tables of their Proportions, suitable for all Falls from 3 to 36 feet.

APPENDIX.—Containing Rules for discovering New Improvements—exemplified in Improving the Art of cleaning Grain, hulling Rice, warming Rooms, and venting Smoke by Chimnies, &c.

EMBELLISHED WITH TWENTY-FIVE PLATES.

BY OLIVER EVANS.

FOURTH EDITION.

PHILADELPHIA:
M. CAREY & SON—CHESNUT STREET.

1821.

PREFACE.

The reason why a book of this kind, although so much wanted, did not sooner appear, may be —because they who have been versed in science and literature, have not had practice and experience in the arts; and they who have had practice and experimental knowledge, have not had time to acquire science and theory, those necessary qualifications for completing the system, and which are not to be found in any one man. Sensible of my deficiencies in both, I should not have undertaken it, was I not interested in the explanation of my own inventions. I have applied to such books and men of science as I expected assistance from, in forming a system of theory; and to practical mill-wrights and millers for the practice; but finding no authors who had joined practice and experience with theory, (except Smeaton whom I have quoted) finding many of their theories to be erroneous, and losing the assistance of the late ingenious William Waring, the only scientific character of my acquaintance, who acknowledged that he had investigated the principles and powers of water acting on mill-wheels, I did not meet the aid I expected in that part.

Wherefore it is not safe to conclude that this work is without error—but that it contains many,

both theoretical, practical, and grammatical; is the most natural, safe, and rational supposition. The reader, whose mind is free and unbiassed by the opinion of others, will be most likely to attain the truth. Under a momentary discouragement, finding I had far exceeded the prescribed limits, and doubtful what might be its fate, I left out several expensive draughts of mills, &c. But since it went to press the prospects have become so encouraging that I may hope it will be well received: Therefore I request the reader, who may prove any part to be erroneous, can point out its defects, propose amendments, or additions; to inform me thereof by letter; that I may be enabled to correct, enrich, and enlarge it, in case it bears another edition, and I will gratefully receive their communications: For if what is known on these subjects by the different ingenious practitioners in America could be collected in one work, it would be precious indeed, and a sufficient guide to save thousands of pounds from being uselessly expended. For a work of this kind will never be perfected by the abilities and labours of one man.

The practical part received from Thomas Ellicott will doubtless be useful, considering his long experience and known genius.

Comparing this with other original, difficult works, with equally expensive plates, the price will be found to be low.

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EXPLANATION OF THE TECHNICAL TERMS, &c. USED IN THIS WORK.

Aperture, The opening by which water issues.

Area, Plane surface, superficial contents.

Atmosphere, The surrounding air.

Algebraic signs used are $+$ for more, or addition. $-$ Less, subtracted. $\times$ Multiplication $\div$ Division. $=$ Equality. $\surd$ The square root of 86^2 for 86 squared, 88^3 for 88 cubed.

Biquadrate, A number twice squared: the biquadrate of 2 is 16.

Corollary, Inference.

Cuboch, A name for the unit or integer of power, being one cubic foot of water multiplied into one foot perpendicular descent.

Cubic foot of water, What a vessel one foot wide and one foot deep will hold.

Cube of a number, The product of the number multiplied by itself twice.

Cube root of a number, Say of 8, is the number, which multiplied into itself twice will produce 8, viz. 2. Or it is that number by which you divide a number twice to quote itself.

Decimal point, set at the left hand of a figure shows the whole number to be divided into tens, as ,5 for 5 tenths; ,57 for 57 hundredths; ,557 for 557 thousandth parts.

Equilibrio, *Equilibrium*.—Equipoise, or balance of weight.

Elastic. Springing.

Friction, The act of rubbing together.

Gravity, That tendency all matter has to fall downwards.

Hydrostatics, Science of weighing fluids.

Hydraulics, Water-works, the science of motion of fluids.

Impulse, Force communicated by a stroke.

Impetus, Violent effort of a body inclining to move.

Momentum, The force of a body in motion.

Maximum, Greatest possible.

Non-elastic, Without spring.

Octuble, Eight times told.

Paradox, Contrary to appearance.

Percussion, Striking a stroke, impulse.

Problem, A question.

Quadruple, Four times, fourfold.

Radius, Half the diameter of a circle.

Right angle, A line square, or perpendicular to another.

Squared, Multiplied into itself; 2 squared is 4.

Theory, Speculative plan existing only in the mind.

Tangent, A line perpendicular or square with a radius touching the periphery of a circle.

Theorem, Position of an acknowledged truth.

Velocity, Swiftness of motion.

Virtual or effective descent of water: See Art. 61.

SCALE FROM WHICH THE FIGURES ARE DRAWN.

PLATE II. Fig. 11, 12, 8 feet to an inch; fig. 19, 10 feet to an inch.
III. Fig. 19, 20, 23, 26, 10 feet to do.
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THE YOUNG MILL-WRIGHT'S AND MILLER'S GUIDE.

PART THE FIRST.

CHAPTER I.

ARTICLE 1.

OF THE FIRST PRINCIPLES OF MECHANICS.

MOTION may be said to be the beginning or foundation of all mechanics; because no mechanical operation can be performed without motion.

AXIOMS; *or, Self-evident Truths.*

1. A body at rest will continue so for ever, unless it is put in motion by some force impressed.*
2. A body in motion will continue so for ever, with the same velocity in the same direction, unless resisted by some force.†
3. The impulse that gives motion, and the resistance that destroys it, are equal.

* This sluggish, inactive principle, or resistance, by which a body inclines to a state of rest, is called Inertia.

† The same principle of inertia, which inclines a body to remain at rest, also inclines it to continue in motion for ever, if once put in motion, and that in a right-lined direction, unless changed by some force: therefore no body, moving in a straight line, can be turned into a curve line, but by some force; the consideration of which may lead us to the knowledge of the true principles of some mills. See the latter part of art. 73.

4. Causes and effects are equal, or directly proportional.

POSTULATUMS; *or, Positions without Proof.*

A quadruple impulse, or moving power, is requisite to communicate double velocity to a body;* therefore a quadruple resistance is requisite to destroy double velocity in a body, by axiom 3d.

The impulse we may call power, and the resistance that it overcomes, the effect produced by that power.

COROLLARY.

Consequently, the powers of bodies in motion, to produce effects, are as the squares of their velocities; that is, a double velocity, in a moving body, produces four times the effect.

ART. 2.

OF THE PRINCIPLES OF MECHANICS.

There are two principles which are the foundation of all mechanical motion and mechanical powers, viz. Gravity and Elasticity; or, Weight and Spring.

By one or the other of these principles or powers, every mechanical operation is performed.

Gravity, in the extent of the word, means every species of attraction; but more especially that species which is common to, and mutual between, all bodies; and is evident between the sun and its planetary attendants, as also the earth and the moon.† But we will only consider it,

* In the course of this work, I shall shew, that a quadruple impulse produces only double velocity. See art. 7 and 46. We should follow philosophers only in the paths of truth; because, if all men are subject to err, even the most eminent philosophers may have erred.

If a theory will not agree with practice, we may suspect it is not true; and the theory of the momentum, or force of bodies in motion, being as their velocities simply, does not agree with practice, with respect to the effects they produce, either in circular motion, art. 13, falling bodies, art. 9, spouting fluids, art. 45, wind on mill-sails, art. 69, therefore we have reason to suspect that this theory may not be true, in every respect.

† It is this attraction of gravity between the heavenly bodies, that keeps up the order of their motion, in their revolution round each other. See Ferguson's Lectures, page 23.

as it relates to that tendency which all bodies on the earth have to fall towards its centre; thus far it concerns the mechanical arts, and its laws are as follows, viz.:

Laws of Gravity.

1. Gravity is common to all bodies, and mutual between them.

2. It is in proportion to the quantity of matter in bodies.

3. It is exerted every way from the centre of attracting bodies, in right-lined directions; therefore all bodies on the earth tend to the centre of gravity of the earth.*

4. It decreases as the squares of the distance increase; that is, if a body, on the earth, was to be removed to double the distance from the centre of gravity of the earth, about 4000 miles high, it would there have but one-fourth of the gravity or weight it had when on the ground: but a small height from the surface of the earth (50, or 100 feet) makes no sensible difference in gravity.†

By the 3d law, it follows, that all bodies descending freely by their gravity, tend towards the earth, in right lines, perpendicular to its surface, and with equal velocities (abating for the resistance of the air) as is evident by the 2d law.‡

* The centre of gravity of a body, is that point on which, if the body be suspended, it will remain at rest in any position; or, it is the centre of the whole weight or matter of the body. Art 14.

† The diameter of the earth is allowed to be about 8000 miles; therefore we may suppose the centre of gravity of the earth to be about 4000 miles from its surface; and any small distance from its surface, such as one mile high, will make no sensible difference in gravity. But when the distance is so great as to bear a considerable proportion to the distance of the centre of gravity of the earth, then the power of gravity will decrease sensibly. Thus, at the distance of the moon, which at a mean, is about 60 semi-diameters of the earth, the power of gravity is to that on the surface of the earth, as 1 to 3600. See Martin's Philosophy.

‡ This resistance will be as the surfaces of the bodies; therefore the smaller the body of equal matter, the greater will be the velocity of its fall. But it has been proved, by experiment, that a feather will fall with the same velocity as a guinea, in vacuo. See Ferguson's Lectures, p. 183.

ART. 3.

ELASTICITY.

Elasticity is that strength or repulsive power, which any body or quantity of matter, being confined or compressed, has to expand itself; such as a spring that is bent or wound up, heated air or steam confined in a vessel, &c. and by it many mechanical operations are performed.

Elasticity, in the full sense of the word, here means every species of repulsion.

The limits of the prodigious power of repulsion which takes place between the particles of heated air and steam, are not yet known. Their effects are seen in the explosion of gunpowder, the bursting and cracking of wood in the fire, &c. In short, in every instance, where steam could not find room to expand itself, it has burst the vessel that confined it, endangering the lives of those who were near it.*

Having premised what was necessary to the right understanding of the science of mechanics, which mostly depends upon the principles of gravitation,

We come to consider the objects thereof, viz. the nature, kinds, and various effects of motion and moving bodies, and the structure and mechanism of all kinds of machines, called mechanical powers, whether simple or compound.

* A worthy and ingenious young man, having prepared a vessel of wrought iron, about 3 inches diameter, and 9 inches long, partly filled with water, had put it into a smith's fire, and was trying some experiments, when the aperture, by which the steam was meant to issue, got stopped by some means (as is supposed) and the vessel burst with noise like a cannon, carried off his right arm, and left it laying across one of the upper beams of the shop, and otherwise desperately wounded him. This prodigious power is applied to raise water out of coal mines, &c. from great depths, in surprising quantities, and to turn mills : it may (in my opinion) be applied to many other useful purposes, which it is not yet applied to.

On this subject much might be said; but as it does not immediately concern this work, perhaps I have said enough to excite the reader to peruse the several late authors on philosophy, who have treated largely on it, and to them I must refer. Also to my new work entitled The Abortion of the Young Steam-engineer's Guide.

CHAPTER II.

ART. 4.

OF MOTION AND ITS GENERAL LAWS.

MOTION is the continual and successive change of space or place, and is either absolute or relative.

Absolute motion is the change of space or place of bodies, such as the flight of a bird, or the motion of a ball projected in the air.

Relative motion is the motion one body has with respect to another, such as the difference of motion of the flight of two birds, or of two ships sailing.*

ART. 5.

Motion is either equable, accelerated, or retarded.

Equable motion is when a body passes over equal distances in equal times.

Accelerated motion, is that which is continually increased; such is the motion of falling bodies.†

Retarded motion, is that which continually decreases; such is the motion of a cannon ball thrown perpendicularly upwards.‡

* If two ships, A and B, move with the same velocity, in the same direction, then their absolute motion is the same, and they have no relative motion, and neither of them will appear to a person on board of the other to move at all. Hence it is, that although the earth is continually revolving about its axis, with a velocity, at the equator, of about 1042 miles in an hour, and round the sun, in continual absolute motion, with a velocity of about 58,000 miles in an hour—yet, as all objects on its surface have the same absolute motion, they appear to be at rest, and not to move at all: therefore all motion of bodies on the earth, appears to us to be absolute motion, when compared with the objects fixed on the earth; yet, if we take into consideration the absolute motion of the earth, all motion on it will appear to be merely relative.

If two ships, A and B, moving with equal velocities, pass each other, then they will appear, to a spectator on board of either, to move with double their respective real velocities.

Hence the reason, why a person, riding against the wind, finds its force greater, and with it, its force less, than it really is.

† A falling body is constantly acted upon by all the power of its own gravity; therefore its motion is continually increased.

‡ A cannon ball, projected perpendicular upwards, is constantly resisted by the whole power of its own gravity; therefore its motion will be conti-

ART. 6.

The momentum or quantity of motion, is all the power or force which a moving body has to strike an obstacle to produce effects, and is equal to that impressed force by which a body is compelled to change its place, by axiom 3, art. 1; which, I think, ought to be distinguished by two names, viz. instant and effective momentums.

1. The instant momentum, or force of moving bodies, is in the compound ratio of their quantities of matter and simple velocities conjointly; that is, as the weight of the body A, multiplied into its velocity, is to the weight of the body B, multiplied into its velocity, so is the instant force of A to the instant force of B. If A has 4lbs. of matter, and 1 degree of velocity, and B has 2lbs. of matter, and 4 degrees of velocity; then the momentum of their strokes will be as 4 is to 8; that is, supposing them to be instantaneously stopped by an obstacle.

2. The effective momentum, or force of moving bodies, is all the effect they will produce by impinging on any yielding obstacle, and is in the compound duplicate ratio of their quantities (or weights) multiplied into the squares of their velocities; that is, as the weight of the body A, multiplied into the square of its velocity, is to the weight of the body B, muliplied into the square of its

nually decreased, and totally stopped as soon as the sum of this resistance amounts to the first impulse, by axiom 3d, art. 1, when it will begin to descend, and its motion will be continually increased by the same power of its own gravity: its motion downwards will be equal to its motion upwards, in every part of its path, and will return to the mouth of the cannon with the velocity and force that it left it; and the time of its ascent and descent will be equal, supposing there was no resistance from the air —but this resistance will make a considerable difference.

From this principle of accelerated motion in falling bodies, may appear the reason, why water poured from the spout of a tea-kettle, will not continue in a stream farther than about two feet, and this stream becomes smaller as it approaches the place where it breaks into drops; because the attraction of cohesion keeps the water together, until the accelerated motion of its fall, which stretches the stream smaller and smaller, overcomes the cohesion, and then it breaks into drops, and these drops become further asunder while they continue to fall; therefore, if the clouds were to empty themselves in torrents, the water would fall on the earth in drops. This may serve to shew the disadvantage of drawing the gate of a water-mill at a great distance from the float-board, but more of this hereafter. See art. 59.

velocity, so is the effective momentum of A to that of B. If A has 2lbs. of matter and 2 degrees of velocity, and B 2lbs. of matter and 4 degrees of velocity, then their effective momentums are as 8 to 32; that is, a double velocity produces a quadruple effect.

ART. 7.

The general laws of motion are the three following, viz.

Law 1. Every body will continue in its present state, whether it be at rest or moving uniformly in a right line, except it be compelled to change that state by some force impressed.*

Law 2. The change of motion or velocity is always proportional to the square root of the moving force impressed, and in a right line with that force, and not as the force directly.†

Law 3. Action and re-action are always equal, and in contrary directions to each other.‡

* By the first law, a body at rest inclines to continue so for ever, by its vis inertia or inactive power, and a body in motion inclines to continue so for ever, passing over equal distances in equal times, if it meets with no resistance, and will move on in a right line. For want of resistance the planets and comets continue their motions undiminished, while moving bowls or wheels are reduced to a state of rest by the resistance of the air, and the friction of the parts on which they move. See Ferguson's Lectures on Mechanics.

It is this friction of the parts, and resistance of the air, which renders it impossible for us to make a perpetual motion; because this friction and resistance are to be overcome, and although it may be reduced to be very small, yet man cannot, with all his art, by mechanical combinations, gain as much power as will overcome it. Philosophers have demonstrated the impossibility of making it; but I think none ought to assert that it will never be found; for there are many perpetual motions in the heavens. If any man would spend his time in this way, it should be to seek for a created power that he might apply to this purpose, and not to create one.

† This is evident, when we consider that a body must fall a quadruple distance to obtain double velocity, by art. 9; and a quadruple head or pressure of fluid produces a double velocity to the spout, by art. 46. The velocity, in both these cases, is as the square root of the impulse, and the impulse as the squares of the velocity, therefore the change of effective motion or velocity will always be as the square root of the impulse or force impressed, and the force impressed as the squares of the velocity or effective motion.

‡ Action and re-action are equal; that is, if a hammer strikes an anvil, the anvil will re-act against the hammer with an equal force to the action of the hammer.

CHAPTER III.

ART. 8.

OF THE MOMENTUM OR FORCE OF BODIES IN MOTION.

1. IF two non-elastic bodies, A and B, fig. 1 ,each having the same quantity of matter, move with equal velocities against each other, they will destroy each other's motion, and remain at rest after the stroke: because their momentums will be equal; that is, if each has 2lbs. of matter and 10 degrees of celerity, their instantaneous momentums will each be 20.

But if the bodies be perfectly elastic, they will recede from each other with the same velocity with which they meet; because action and re-action are equal, by the 3d general law of motion, art. 7.*

2. If two non-elastic bodies, A and B, fig. 2, moving in the same direction with different velocities, impinge on each other, they will (after the stroke) move on together with such velocity, as being multiplied into the sum of their weights, will produce the sum of their instant momentums which they had before the stroke; that is, if each weigh 1lb. and A has 8 and B 4 degrees of celerity, the sum of their instant momentums will be 12, then, after the stroke, their velocity will be 6; which, multiplied into their quantity of matter 2, produces 12, the sum of their instant momentums. But if they had been elastic, then A would have moved with 4 and B

The action of our feet against the ground, and the re-action of the ground against our feet, are equal.

The action of the hand to project a stone, and the re-action of the stone against the hand, are equal.

If a cannon weighing 6400 lbs. gives a 24 lb. ball a velocity of 640 feet per second, the action of the powder on the ball, and its re-action against the cannon, are equal; and if the cannon has liberty to move, it will have a velocity, which multiplied into its weight, will be equal to the velocity of the ball multiplied by its weight; their instant momentums are always equal. See Martin's Philosophy.

* This shews that non-elastic bodies communicate only half their original force; because the force required to cause the bodies to recede from each other, is equal to the force that gave them velocity to meet; and the force that caused the body to recede with velocity 10, is equal to the force that checked velocity 10.

with 8 degrees of velocity after the stroke, and the sum of their instant momentums would be 12, as before.*

3. If a non-elastic body A, with quantity of matter 1, and 10 degrees of velocity, strike B at rest, of quantity of matter 1, they will both move on together with velocity 5; but if they be elastic, B flies off with velocity 10, and A remains at rest, by 3d general law of motion, art. 7.† It is universally true, that whatever instant momentum is communicated to a body, is lost by the body that communicates it.

4. If the body A, fig. 4, receive two strokes or impulses at the same time, in different directions, the one sufficient to propel it from A to B, and the other to propel it from A to D, in equal time, then this compound force will propel it in the diagonal line A C, and it will arrive at C in the same time that it would have arrived at B or D, by one impulse only; and the projectile force of these strokes are as the squares of the sides of the parallelogram, by law 2, art. 7.‡

* Because elastic bodies impinging, recede, after the stroke, with the same velocity with which they meet: therefore, a heavy body in motion, impinging on a lighter body at rest, will give it a greater velocity than that with which it was struck; for if the heavy body be not stopped, but move forward after the stroke, with a certain velocity, that velocity, added to the velocity before the stroke, will be the velocity of the lighter body.

† This also shews evidently, that non-elastic bodies communicate only half their force. A knowledge of this is of great use in establishing a true theory of water-mills.

‡ This doctrine of the momentum of bodies in motion, and communication of motion, being as their velocities simply, was taught by Sir Isaac Newton, and has been received by his followers to this day; which appears to be true, where the whole force is instantaneously spent or communicated: therefore I have changed the term to instant momentum. I have tried the experiment, by causing different weights to strike each other with different velocities, both on the principle of pendulums, and by causing them to move in horizontal circles; and, in both cases, 4 lbs. with velocity 1, balanced 2 lbs. with velocity 2; their momentums each were 4: so that the theory appears to be proved to be true. Yet I think we have reason to doubt its being true in any other sense; because it does not agree with practice. All the bodies we put in motion, to produce effects, produce them in proportion to the squares of their velocities, or nearly, as will appear in the course of this work. But I fear I shall draw on me the ridicule of some, if I should doubt a theory long established; but I think we should follow others only in the paths of truth. Doubtless Sir Isaac meant the force to be instantly spent: and I have understood that the Dutch and Italian philosophers have held and taught, these 100 years past, that the momentum of bodies in motion, is as the squares of their velocities; and I must confess it appears to be really the case, with respect to the effects they produce; which is generally as their quantity or weight

5. If a perfect elastic body be let fall 4 feet, to strike a perfect elastic plain, by the laws of falling bodies, art. 9, it will strike the plain with a velocity of 16,2 feet per second, and rise, by its re-action, to the same height from whence it fell, in half a second: if it falls 16 feet, it will strike with a velocity of 32,4 feet, and rise 16 feet in one second. Now, if we call the rising of the body the effect, we shall find that a double velocity, in this case, produces a quadruple effect in double time. Hence it appears, that a body moving through a resisting medium, with a double velocity, will continue in motion a double time, and go 4 times the distance; which will be a quadruple effect.*

Of Non-elasticity in impinging Bodies.

1. If A and B, fig. 3, be two columns of matter in motion, meeting each other, and equal in non-elasticity,

multiplied into the squares of their velocities. I found it impossible to reconcile the theory of the force of bodies in motion, being as their simple velocities, to the laws of circular motion, art. 13, where a double velocity produces a quadruple central force; of falling bodies, art. 9, where the velocity is as the square root of the impulse or distance fallen, and the effects as the squares of the velocities; of projectiles, where a double velocity produces a quadruple randum, art. 12; of bodies descending on inclined plains, art. 10, where the velocities are as the square roots of the perpendicular descents, and the effects as the squares of their velocities; of spouting fluids, art. 45, where their velocities are as the square roots of their perpendicular heights or pressures, and their effects as the squares of their velocities, with equal quantities; of wind on mill-sails, art. 69, where the effects are as the cube of the velocity of the wind; because here the quantity is as the velocity, and the effect of equal quantities being as the squares of the velocity, amounts the effects to be as the cubes.

But when I discovered that a quadruple impulse was requisite to give double velocity, both in falling bodies and spouting fluids, and, by axiom 3, the power that produced a motion in a body, and the power that destroyed said motion, were equal, I concluded that the effects produced by bodies in motion, were as the squares of their velocities; and then I found the whole theory to agree with practice. Hereafter I shall say, that the effective momentum, or force of bodies in motion, is as the squares of their velocities.

* We should pay no regard to time, in calculating the effective force of bodies in motion. Because, if 1 lb. of matter move with 1 degree of velocity, it will produce a certain effect (before it ceases moving) in an unknown time. Every other pound of matter, moving with equal velocity, will produce an equal effect in equal time. But if each pound of matter move with double velocity, it will produce 4 times the effect, but requires a double time; which difference in time no way affects the sum total of the effects of the matter put in motion to move any practical machine. Therefore we should totally leave time out of this calculation, seeing it tends to lead us into errors.

quantity, and velocity, they will meet at the dotted line e e, destroy each other's motion, and remain at rest, provided none of their parts separate.

2. But if A is elastic, and B non-elastic, they will meet at e e, but B will give way by battering up, and both will move a little further; that is, half the distance that B shortens.

3. But if B is a column of fluid, and when it strikes A, flies off in a lateral perpendicular direction, then whatever is the sum total of the momentums of these particles laterally, has not been communicated to A; therefore A will continue to move, after the stroke, with that said momentum.

4. But with what proportion of the striking velocity the fluid, after the stroke, will move in the lateral direction, I do not find determined; but from small experiments I have made (not fully to be relied on) I suppose it to be more than one half; because water falling four feet, and striking a horizontal plain, with 16,2 feet velocity, will cast some few drops to the distance of 9 feet (say 10 feet, allowing one foot to be lost by friction, &c.) which we must suppose take their direction at an angle of 45 degrees, because it is shewn in Martin's Philosophy, page 135, Vol. I, that a body projected at an angle of 45 degrees will describe the greatest possible horizontal randum; also, that a body falling 4 feet, and reflected with its acquired velocity 16,2 feet, at 45 degrees, will reach 16 feet horizontal randum, or 4 times the distance of the fall. Therefore, by this, 1-4 of 10 feet, equal to 2,5 feet, is the fall that will produce the velocity that produced it, viz. Velocity 12,64 feet per second, about 3-4 of the striking velocity.

5. And if the force of striking fluids be as the squares of their velocities, as proved in art. 67, by experiment, and demonstrated by art. 46; then the ratio of the force of this side velocity, 12,64 feet per second, is to the force of forward velocity, as 160 to 256, more than half (about ,6) of the whole force is here lost by non-elasticity.

6. This side force cannot be applied to produce any further forward force, after it has struck the first obstacle;

because its action and re-action balance each other afterwards: which I demonstrate by fig. 27.

Let A be an obstacle, against which the column of water G A, of quantity 16 and velocity per second 16, strikes; as it strikes A, suppose it to change its direction, at right angles, with 3-4 velocity, and strike B B; then change again, and strike forward against C C, and backwards against D D: then again in the side direction E E; and again in the forward and backward directions, all of which counteract each other, and balance exactly.

Therefore, if we suppose the obstacle A to be the float of an undershot water-wheel, the water can be of no further service, in propelling it, after the first impulse, but rather a disadvantage; because the elasticity of the float will cause it to rebound in a certain degree, and not keep fully up with the float it struck, but re-act back against the float following; therefore it will be better to let it escape freely as soon as it has fully made the stroke, but not sooner, as it will require a certain space to act in, which will be in direct proportion to the distance between the floats.

7. From these considerations, we may conclude, that the greatest effect to be obtained from striking fluids, will not amount to more than half the power that gives them motion; but much less, if they be not applied to the best advantage: and that the force of non-elastic bodies, striking to produce effects, will be in proportion to their non-elasticity.

CHAPTER IV.

ART. 9.

OF FALLING BODIES.

BODIES descending freely by their gravity, in vacuo, or in an unresisting medium, are subject to the following laws:

1st. They are equably accelerated.*

* It is evident, that in every equal part of time, the body receives an impulse from gravity, that will propel it an equal distance, and give it an equal additional velocity; therefore it will produce equal effects in equal times, and their velocity will be proportioned to the time.

2d. Their velocity is always in proportion to the time of their fall, and the time is as the square root of the distance fallen.*

3d. The spaces through which they pass, are as the square of the times or velocities.† Therefore,

4th. Their velocities are as the square root of the space descended through;‡ and their force, to produce effects, as their distances fallen directly.

5th. The space passed through the first second, is very nearly 16,2 feet, and the velocity acquired, at the lowest point, is 32,4 feet per second.

6th. A body will pass through twice the space, in a horizontal direction, with the last acquired velocity of the descending body, in the same time of its fall.§

7th. The total sum of the effective impulse acting on them to give them velocity, is in direct proportion to the space descended through,|| and their velocity being as the square root of the space descended through; or, which is the same, as the square root of the total impulse. Therefore,

8th. Their momentums, or force to produce effects, are as the squares of their velocities,¶ or directly as their

* If the velocity, at the end of one second, be 32,4 feet, at the end of two seconds it will be 64,8, at the end of three seconds 97,2 feet per second, and so on.

† That is, as the square of 1 second is to the space passed through 16,2, so is the square of 2 seconds, which is 4, to 64,8 feet, passed through at the end of 2 seconds, and so on, for any number of seconds. Therefore the spaces passed through at the end of every second, will be as the square numbers 1, 4, 9, 16, 25, 36, &c. and the spaces passed through, in each second separately, will be as the odd numbers 1, 3, 5, 7, 9, 11, 13, 15, &c.

‡ That is, as the square root of 4, which is 2, is to 16,2, the velocity acquired in falling four feet: so is the square root of any other distance, to the velocity acquired, in falling that distance.

§ That is, suppose the body as it arrives at the lowest point of its fall, and has acquired its greatest velocity, was to be turned in a horizontal direction, and the velocity to continue uniform, it would pass over double the distance, in that direction that it had descended through in the same time.

|| This is evident from the consideration, that in every equal part of distance it descends through, it receives an equal effective impulse from gravity. Therefore 4 times the distance, gives 4 times the effective (but not instant) impulse.

¶ This is evident, when we consider, that a quadruple distance or impulse, produces only double velocity, and by axiom 3 a quadruple resistance will be required, to stop double velocity; consequently their force is

distances fell through; and the times expended in producing the effects, are as the square root of the distance fallen through.*

9th. The resistance they meet with in any given time, in passing through a resisting medium, is as their surfaces, and as the cubes of their velocities.†

as the squares of their velocities, which brings them to be directly as their distances descended through: and this agrees with the second law of spouting fluids. Art. 45.

* That is, if a body fall 16 feet, and strike a non-elastic body, such as hot iron, soft lead, clay, &c. it will strike with velocity 32, and produce a certain effect in a certain time. Again, if it fall 64 feet, it will strike with velocity 64, and produce a quadruple effect, in a double time; because, if a perfectly elastic body fall 16 feet in one second of time, and strike a perfectly elastic plain, with velocity 32 feet, it will rise 16 feet in one second of time. Again, if the body fall two seconds of time, it will fall 64 feet, and strike with velocity 64, and rise 64 feet in two seconds of time. Now, if we call the rising of the body the effect of the striking velocity (which it really is) then all will appear clearly. But any thing here advanced, if contrary to the opinion of many learned and ingenious authors, ought to be doubted, unless known to agree with practice.

† This is evident when we consider,

1. That it is a proportion of the surfaces, that meets the resistance; and,

2. That a double velocity strikes a double quantity of resisting particles in the same time.

3. That a double velocity strikes each particle with double the instant, and four times the effective force, by art. 6.

Therefore, the instant resistance is as the squares of their velocities, and will soon amount to the whole force of gravity, and reduce the motion to be uniform. This is the reason why hail and rain falls with such moderate force; whereas if it was not for the resistance of the air, they would prove fatal to those they fall upon. Compare this with the effect of wind on mill-sails, proved by experiment, to be as the cubes of the velocity, art. 69, and with the effects of spouting fluids, proved to be as the cubes of their velocities, with equal apertures. Art. 67, and 7th law of spouting fluids.

Again, consider that the solid content of bodies decreases, as the cubes of their diameters, while their surfaces decrease only as the squares of their diameters; consequently the smaller the body, the greater the resistance, in proportion to its weight: and this is the reason why heavy bodies, reduced to dust, will float in the air; as, likewise, feathers, and many other bodies of great surface and little matter. This seems to shew, that air is, perhaps, as heavy as any other matter whatever, of an equal degree of fineness or smallness of particles.

These are the laws of falling bodies supposing them to fall in vacuo, or in an unresisting medium; and without considering that gravity increases, as the square of the distance from the centre of gravity of the attracting power decreases (4. law of gravity, art. 2;) because any small distance, such as comes in our practice, will make no sensible difference. But as they fall in the air, which is a medium, of great resistance, the instant resistance is as the opposing surfaces of the falling body, and as the squares of their velocities, their motion will greatly differ from these laws, in falling great distances, or with light bodies; but in small distances, such as 30 feet or less, and heavy bodies, the difference will be imperceptible in common practice.

A TABLE

OF THE

MOTION OF FALLING BODIES.

SUPPOSED IN VACUO.

Distance passed through in Feet.	The velocity acquired by the fall, in feet and parts, counted per second.	Seconds of time that a body is supposed to be falling.	Distance passed through in said time, in feet and parts.	Velocity per second acquired at the end of every second, in feet and parts.
1	8.1	.125	.25	4.
2	11.4	.25	1.01	8.1
3	14.	.5	4.05	16.2
4	16.2	.75	9.11	24.3
5	18.	1	16.2	32.4
6	19.84	2	64.8	64.8
7	21.43	3	145.8	97.2
8	22.8	4	259.2	129.6
9	24.3	5	305.	162.
10	25.54	6	583.2	194.4
11	26.73	7	793.8	226.8
12	28.	8	1036.8	259.2
18	29.16	9	1312.2	291.6
14	30.2	10	1620.	324.
15	31.34	30	14580.	972.
16	32.4	60	58320.	1944.
17	33.32			
18	34.34			
19	35.18			
20	36.2			
21	37.11			
36	48.6			
49	56.7			
64	64.8			
100	81			
144	97.2			

A SCALE

OF THE

MOTION OF FALLING BODIES.*

	16.2 feet is the space fallen through the 1st second, by law 5, which let be equal to - - - - - -			1
	Which is also the whole space fallen through at the end of the 1st second, which let be equal to - - -	1		
16.2	32.4 feet per second is the velocity acquired by the fall, ditto - - - - - - - - - -		1	
1	——.——. a			
	48.6 feet is the space fallen through the 2d second, ditto			3
48	64.8 feet do. at the end of 2 seconds, ditto - -	4		
b	64.8 feet is the velocity per second, acquired at the end of the 2d second, ditto - - - - - - - -		2	
3	——.——.—— ——. c			
	81. feet is the space fallen through the 3d second of time, do.			5
	145.8 feet ditto in 3 seconds of time, ditto - -	9		
d	97.2 feet is the velocity acquired by the fall at the end of 3 seconds, ditto - - - - - - - - -		3	
5	—— —— ——.——.——.——. e			
	113.4 feet is the space fallen through in the 4th second of time, ditto - - - - - - - - - -			7
	259.2 feet ditto in 4 seconds, ditto - - - - -	16		
f	129.6 feet per second, is the velocity acquired at the end of 4 seconds, ditto - - - - - - - - -		4	
7	——.—— ——.——.——.——.——.——. g			

* In this table, the first column contains the total space fallen through, which is as the squares of the times or velocities, by law 3. The second column contains the velocity acquired, which is as the square root of the distance fallen, and as the time of the fall, by laws 2 and 4. The third column contains the space fallen through each second, which is as the odd numbers.

This scale shews at one view, all the laws to be performed by the falling body o, which falls from o to 1, 16,2 feet, the first second, and acquires a velocity that would carry it 32,4 feet, from 1 to a, the next second, by laws 5 and 6; this velocity would also carry it down to b in the same time, but its gravity, producing equal effects, in equal times, will accelerate it so much as to take it to 3 in the same time, by law 1. It will now have a velocity of 64,8 feet per second, that will take it to c horizontally, or down to d, but gravity will help it on to 5 at the same time. Its velocity will now be 97,2 feet, which will take it horizontally to e, or down to f, but gravity will help it on to 7; and its last acquired velocity will be 129,6 feet per second from 7 to g.

If either of these horizontal velocities be continued, the body will pass over double the distance it fell, in the same time, by law 6.

Again, if o be perfectly elastic, and falling, strikes a perfect elastic plane, either at 1, 3, 5 or 7, the effective force of its stroke will cause it to rise again to o in the same space of time it took to fall.

Which shews, that in every equal part of distance, it received an equal effective impulse from gravity, and that the total sum of their effective impulse is as the distance fallen directly—and the effective force of their strokes will be as the squares of their velocities, by laws 7 and 8.

CHAPTER V.

ART. 10.

OF BODIES DESCENDING INCLINED PLANES AND CURVED SURFACES.

BODIES descending inclined planes and curved surfaces, are subject to the following laws:

1. They are equably accelerated, because their motion is the effect of gravity.

2. The force of gravity propelling the body A, fig. 5, to descend an inclined plane A D, is to the absolute gravity

of the body, as the height of the plane A C is to its length A D.

3. The spaces descended through are as the squares of the times.

4. The times, in which the different planes A D, A H, and A I, or the altitude A C, are passed over, are as their lengths respectively.

5. The velocities acquired in descending such planes, in the lowest points D, H, I or C, are all equal.

6. The times and velocities of bodies descending through planes alike inclined to the horizon, are as the square roots of their lengths.

7. Their velocities, in all cases, are as the square roots of their perpendicular descent.

From these laws or properties of bodies descending inclined planes, are deduced the following corollaries, viz.

1. That the time, in which a body descends through the diameter A C, or any chord A a, A e, or A i, are equal. Hence,

2. All the chords of a circle are described in equal times.

3. The velocity acquired in descending through any arch, or chord of an arch, of a circle, as at C, in the lowest point C, is equal to the velocity that would be acquired in falling through the perpendicular height F C.

The motion of pendulums have the same properties, the rod or string acting as the smooth curved surface.

For demonstration of these properties, see Martin's Philosophy, vol. i. page 111—117.

CHAPTER VI.

ART. 12.

OF THE MOTION OF PROJECTILES.

A PROJECTILE is a body thrown or projected in any direction; such as a stone from the hand, water spouting from any vessel, a ball from a cannon, &c. fig. 6.

Every projectile is acted on by two forces at the same time, viz. the Impulse and the Gravity.

By the impulse, or projectile force, the body will pass over equal distances, A B, B C, &c. in equal times, by 1st general law of motion, art. 7, and by gravity, it descends through the spaces A G, G H, &c. which are as the squares of the times, by 3d law of falling bodies, art. 9. Therefore, by these forces compounded, the body will describe the curve A Q, called a parabola; and this will be the case in all directions, except perpendicular; but the curve will vary with the elevation, yet it will still be what is called a parabola.

If the body is projected at an angle of 45 degrees elevation, it will be thrown to the greatest horizontal distance possible; and, if projected with double velocity, it will describe a quadruple randum.

For a full account and demonstration, see Martin's Phil. vol. i. p. 128—135.

CHAPTER VII.

ART. 13.

OF CIRCULAR MOTION AND CENTRAL FORCES.

IF a body A, fig. 7, be suspended by a string A C, and caused to move round the centre C, that tendency which it has to fly from the centre, is called the centrifugal force; and the action of the string upon the body, which constantly solicits it towards the centre, and keeps it in the circle A M, is called the centripetal force. Speaking of these two forces indefinitely, they are called central forces.*

The particular laws of this species of motion, are,

* It may be well to observe here, that this central force is no real power, but only an effect of the power that gives the body the motion. Its inertia causes it to recede from the centre, and fly off in a direct tangent line, with the circle it moves in. Therefore this central force can neither add to, nor diminish from, the power of any mechanical or hydraulic engine, unless it be by friction and inertia, where water is the moving power and the machine changes its direction.

1. Equal bodies describing equal circles in equal times, have equal central forces.

2. Unequal bodies describing equal circles in unequal times, their central forces are as their quantities of matter multiplied into their velocities.

3. Equal bodies describing unequal circles in equal times, their velocities and central forces are as their distances from their centres of motion, or as the radius of their circles.*

4. Unequal bodies describing unequal circles in equal times, their central forces are as their quantities of matter multiplied into their distance from the centre or radius of their circles.

5. Equal bodies describing equal circles in unequal times, their central forces are as the squares of their velocities; or, in other words, a double velocity generates a quadruple central force.† Therefore,

6. Unequal bodies describing equal circles in unequal times, their central forces are as their quantities multiplied into their velocities.

* This shews, that when mill-stones are of unequal diameters, and revolve in equal times, the largest would have the draught of their furrows less, in proportion as their central force is more, which is inverse proportion; also that the draught of a stone should vary, and be in inverse proportion to the distance from the centre. That is, the greater the distance the less the draught.

Hence we conclude, that if stones revolve in equal times, their draught must be equal next the centre: that is, so much of the large stones, as is equal to the size of the small ones, must be of equal draught. But that part which is greater, must have less draught in inverse proportion, as the distance from the centre is greater, the furrows must cross at so much less angle; which will be nearly the case (if their furrows lead to an equal distance from their centres) at any considerable distance from the centre of the stone; but near the centre the angles become greater than the proportion: if the furrows be straight, as appears by the lines, g 1, h 1, g 2, h 2, g 3, h 3, in fig. 1, pl. XI. the angles near the centre are too great, which seems to indicate, that the furrows of mill-stones should not be straight, but a little curved; but what this curve should be is very difficult to determine exactly by theory. By theory it should be such as to cause the angle of furrows crossing, to change in inverse proportion with the distance from the centre, which will require the furrows to curve more, as they approach the centre.

† This shews that mill-stones of equal diameters, having their velocities unequal, should have the draught of their furrows, as the square roots of their number of revolutions per minute. Thus, suppose the revolutions of one stone to be 81 per minute, and the mean draught of the furrows 5 inches, and found to be right; the revolutions of the other to be 100; then to find the draught, say, As the square root of 81, which is 9, is to the 5 inches draught; so is the square root of 100, which is 10, to 4,5 inches, the draught required (by inverse proportion) because the draught must decrease as the central force increases.

7. Equal bodies describing unequal circles with equal celerities, their central forces are inversely as their distances from the centre of motion or radius of the circles.*

8. Equal bodies describing unequal circles, having their central forces equal; their periodical times are as the square roots of their distances.

9. Therefore the squares of the periodical times are proportional to the cubes of their distances, when neither the periodical times nor the celerities are given. In that case,

10. The central forces are as the squares of the distances inversely.†

* That is, the greater the distance the less the central force. This shews that mill-stones of different diameters, having their peripheries revolving with equal velocities, should have the angle of draught, with which their furrows cross each other, in inverse proportion to their diameters, because their central forces are as their diameters, by inverse proportion, directly; and the angle of draught should increase, as the central force decreases; and decrease, as it increases.

But here we must consider, that, to give stones of different diameters equal draughts, the distance of their furrows from the centre, must be in direct proportion to their diameters. Thus, as 4 feet diameter is to 4 inches draught, so is 5 feet diameter to 5 inches draught. To make the furrows of each pair of stones cross each other at equal angles, in all proportional distances from the centre, see fig. 1. plate XI. where g b, g d, g f, h a, h c, and h e, shew the direction of the furrows of the 4, 5, and 6 feet stones, with their proportional draughts; now it is obvious that they cross each other at equal angles, because the respective lines are parallel, and cross in each stone, near the middle of the radius, which shews that in all proportional distances, they cross at equal angles, consequently their draughts are equal.

But the draught must be further increased, with the diameter of the stone, in order to increase the angle of draught in the inverse ratio, as the central force decreases.

To do which, say: If the 4 feet stone has central furce equal 1, what central force will the 5 feet stone have? Answer: ,8 by the 7th law.

Then say, If central force 1 requires 5 inches draught, for a 5 feet stone, what will central force ,8 require? Answer: 6,25 inches draught. This is, supposing the verge of each stone to move with equal velocity. This rule may bring out the draught nearly true, provided there be not much difference between the diameter of the stones. But it appears to me, that neither the angles with which the furrows cross, nor the distance of the point from the centre, to which they direct, is a true measure of the draught.

† These are the laws of circular motion and central forces. For experimental demonstrations of them, see Ferguson's Lectures on Mechanics, page 27 to 47.

I may here observe that the whole planetary system is governed by these laws of circular motion and central forces. Gravity acting as the string, and is the centripetal force; and as the power of gravity decreases, as the square of the distance increases, by the 4th law of gravity, art. 2; and as the centripetal and centrifugal forces must always be equal, in order to keep the body in a circle. Hence appears the reason why the planets most

CHAPTER VIII.

ART. 14.

OF THE CENTRES OF MAGNITUDE, MOTION, AND GRAVITY.

THE centre of magnitude is that point which is equally distant from all the external parts of a body.

2. The centre of motion is that point which remains at rest, while all other parts of the body move round it.

3 The centre of gravity of bodies, is of great consequence to be well understood, it being the principle of much mechanical motion, and possesses the following particular properties:

1. If a body is suspended on this point, as its centre of motion, it will remain at rest in any position.

2. If a body is suspended on any other point than its centre of gravity, it can rest only in such position, that a right line drawn from the centre of the earth through the centre of gravity, will intersect the point of suspension.

3. When this point is supported, the whole body is kept from falling.

4. When this point is at liberty to descend, the whole body will fall.

5. The centre of gravity of all homogeneal bodies, as squares, circles, spheres, &c. is the middle point in a line connecting any two opposite points or angles.

remote from the sun have their motion so slow, while those near him have their motions swift; because their celerities must be such as to create a centrifugal force equal to the attraction of gravity.

I may here observe, that modern philosophers begin to doubt the existence of inertia, as defined by Newton, to be different and independent from gravity, but seem to conclude that they are both one thing; but when we consider that the whole force of gravity is exerted as centripetal force, to keep the heavenly bodies in a circle, it cannot be that same power, cause, or principle, that causes the bodies to continue their motion, unless one cause can produce two effects each equal to itself, contrary to axiom 4. Again we may consider, that gravity decreases, as the squares of the distance of the body from the attracting power increases, but inertia is the same every where; and if we suppose the body to be removed out of the sphere of attraction of gravity, there will be no gravity at all, yet inertia will act in its full power, to continue the motion or rest of a body, by axiom 1 and 2. Hence in this light gravity and inertia appear to be two very different principles, and ought to be distinguished by different names: but here we may dispute about words, for in other lights they appear to be the very same thing.

6. In a triangle, it is in a right line drawn from any angle to bisect the opposite side, at the distance of one third of its length from the side bisected.

7. In a hollow cone, it is in a right line passing from the apex to the centre of the base, and at the distance of one third of the side from the base.

8. In a solid cone, it is one fourth the side from the base, in a line drawn from the apex to the centre of the base.

Hence the solution of many curious phænomena, as, why many bodies stand more firmly on their bases than others; and all bodies will fall, when their centre of gravity falls without their base.

Hence appears the reason, why wheel-carriages, loaded with stones, iron, or any heavy matter, will not overturn so easy, as when loaded with wood, hay, or any light matter; for when the load is not higher than a b, fig. 12, the centre of gravity will fall within the centre of the base at c; but if the load is as high as d, it will then fall outside the base of the wheels at e, consequently it will overturn. From this appears the error of those, who hastily rise in a coach or boat, when likely to overset, thereby throwing the centre of gravity more out of the base, and increasing the danger.

CHAPTER IX.

ART. 15.

OF THE MECHANICAL POWERS.

HAVING now premised and considered all that is necessary for the better understanding those machines called mechanical powers, we come to treat of them, and they are six in number, viz.

The Lever, the Pulley, the Wheel and Axle, the Inclined Plane, the Wedge, and the Screw.

They are called Mechanical Powers, because they increase our power of raising or moving heavy bodies; and, although they are six in number, they seem to be reducible to one, viz. the Lever, and appear to be governed by one simple principle, which I shall call the First General Law of Mechanical Powers; which is this, viz. the momentums of the power and weight are always equal, when the engine is in equilibrio.

Momentum, here means the product of the weight of the body multiplied into the distance it moves; that is, the power multiplied into its distance moved, or into its distance from the centre of motion, or into its velocity, is equal to the weight multiplied into its distance moved, or into its distance from the centre of motion, or into its velocity; or, the power multiplied into its perpendicular descent, is equal to the weight multiplied into its perpendicular ascent.

The Second General Law of Mechanical Powers, is,

The power of the engine, and velocity of the weight moved, are always in the inverse proportion to each other; that is, the greater the velocity of the weight moved, the less it must be; and the less the velocity, the greater the weight may be, and that universally in all cases. Therefore,

The Third General Law is,

Part of the original power is always lost in overcoming friction, inertia, &c. but no power can be gained by engines, when time is considered in the calculation.

In the theory of this science, we suppose all planes to be perfectly smooth and even, levers to have no weight, cords to be perfectly pliable, and machines to have no friction: in short, all imperfections are to be laid aside, until the theory is established, and then proper allowances are to be made.

ART. 16.

Of the Lever.

A bar of iron, wood, &c. one part of which is supported by a prop, and all other parts turn or move on that prop, as their centre of motion, is called a lever; and its length, on each side of the prop, is called its arms; the velocity or motion of every part of these arms is directly as its distance from its centre of motion, by 3d law of circular motion.

The lever—Observe the following laws:

1. The power and weight are to each other, as their distances from the centre of motion, or from the prop, respectively.*

2. The power is to the weight, as the distance the weight moves is to the distance the power moves, respectively.†

3. The power is to the weight, as the perpendicular ascent of the weight is to the perpendicular descent of the power.‡

4. Their velocities are as their distances from their centre of motion, by 3d law of circular motion.

These simple laws hold universally true in all mechanical powers or engines; therefore it is easy (from these simple principles) to compute the power of any engine, either simple or compound; for it is only to find how much swifter the power moves than the weight, or how much farther it moves in the same time; and so much is the power, (and time of producing it) increased by the help of the engine.

* That is, the power P, fig. 8. Plate I. which is 1 multiplied into its distance B C, from the centre 12, is equal to the weight 12 multiplied into its distance AB 1, each product being 12.

† That is, the power multiplied into its distance moved, is equal to the weight multiplied into its distance moved.

‡ That is, the power multiplied into its perpendicular descent, is equal to the weight multiplied into its perpendicular ascent.

ART. 17.

GENERAL RULES FOR COMPUTING THE POWER OF ANY ENGINE.

1. Divide either the distance of the power from its centre of motion, by the distance of the weight from its centre of motion. Or,

2. Divide the space passed through by the power, by the space passed through by the weight. This space may be counted either on the arch described, or perpendiculars. And the quotient will shew how much the power is increased by the help of the engine.

Then multiply the power applied to the engine, by that quotient, and the product will be the power of the engine, whether simple or compound.

EXAMPLES.

Let A B C, Plate I. fig. 8, represent a lever; then to compute its power, divide the distance of the power P from its centre of motion B C 12, by the distance of the weight W, A B 1, and the quotient is 12: the power is increased 12 times by the engine; which, multiply by the power applied 1, produces 12, the power of the engine at A, or the weight W, that will balance P, and hold the engine in equilibrio. But suppose the arm A B to be continued to E, then, to find the power of the engine, divide the distance B C 12, by B E 6; and the quotient is two; which multiplied by 1, the power applied, produces 2, the power of the engine, or weight w to balance P.

Or divide the perpendicular descent of the power C D equal 6, by the perpendicular ascent E F equal 3; and the quotient 2, multiplied by the power P equal 1, produces 2, the power of the engine at E.

Or divide the velocity of the power P equal 6, by the velocity of the weight w equal 3; and the quotient 2, multiplied by the power 1, produces 2, the power of the engine at E. If the power P had been applied at 8, then it would have required to have been 1 1-2 to balance W, or w: because 1 1-2 times 8 is 12, which is the momentum of both weights W and w. If it had been ap-

plied at 6, it must have been 2; if at 4, it must have been 3; and so on for any other distance from the prop or centre of motion.

ART. 18.

THERE ARE FOUR KINDS OF LEVERS.

1. The common kind, where the prop is placed between the weight and power, but generally nearest the weight.

2. When the prop is at one end, the power at the other, and the weight between them.

3. When the prop is at one end, the weight at the other, and the power applied between them.

4. The bended lever, which differs only in form, but not in properties, from the others.

Those of the first and second kind have the same properties and powers, and are real mechanical powers, because they increase the power; but the third kind is a decrease of power, and only used to increase velocity, as in clocks, watches, and mills, where the first mover is too slow, and the velocity increased by the gearing of the wheels.

The machinery of the human frame is composed of the last kind of lever; for when we lift a weight by the hand, resting the elbow on any thing, the muscle that exerts the force to raise the weight, is fastened at about one tenth of the distance from the elbow to the hand, and must exert a force ten times as great as the weight raised; therefore, he that can lift 56lbs. with his arm at a right angle at the elbow, exerts a force equal to 560lbs. by the muscles of his arm. Wonderful is the power of the muscles in these cases. Here appears the reason, why men of low stature are stronger than those of high, in proportion to their thickness, as is generally the case.

ART. 19.

COMPOUND LEVER.

If several levers are applied to act one upon another, as 2 1 3, in fig. 9, Plate I. where No. 1 is of the first

kind, No. 2 of the second, and No. 3 of the third. The power of these levers, united to act on the weight w, is thus found by the following rule, which will hold universally true in any number of levers united, or wheels (which is similar thereto) acting upon one another.

RULE.

1st. Multiply the power P, into the length of all the driving levers successively, and note the product.

2d. Then multiply all the leading levers into one another successively, and note the product.

3d. Divide the first product by the last, and the quotient will be the weight w, that will hold the machine in equilibrio.

This rule is founded on the first law of the lever, art. 16, and on this principle, viz.

If the weight w, and power P, are such, that when suspended on any compound machine, whether of levers united, or of wheels and axles, they hold the machine in equilibrio. Then, if the power P, is multiplied into the radius of all the driving wheels, or lengths of the driving levers, and the product noted; and the weight w multiplied into the radius of all the leading wheels, or length of the leading levers, and the product noted; these products will be equal. If we had taken the velocities or circumferences of the wheels, instead of their radius, they would have been equal also.

On this principle is founded all rules for calculating the power and motion of wheels in mills, &c. See art. 20 and 74.

EXAMPLES.

Given, the power P equal to 4, on lever 2, at 8 distance from the centre of motion. Required, with what force lever 1, fastened at 2 from the centre of motion of lever 2, must act, to hold the lever 2 in equilibrio.*

* In order to abbreviate the work, I shall hereafter use the following Algebraic signs, viz.

By the rule, 4×8 the length of the long arm, is 32, and divided by 2, the length of the short arm, quotes 16, the force required.

Then 16 on the long arm, lever 1, at 6 from the centre of motion. Required, the weight on the short arm, at 2, to balance it.

By the rule, $16\times 6=96$, which divided by 2, the short arm, quotes 48, for the weight required.

Then 48 is on the lever 3, at 2 from the centre. Required, the weight at 8 to balance it.

Then $48\times 2=96$, which divided by 8, the length of the long arm, quotes 12, the weight required.

Given, the power $P=4$, on one end of the combination of levers. Required, the weight w, on the other end, to hold the whole in equilibrio.

Then by the rule, $4\times 8\times 6\times 2=384$ the product of the power multiplied into the length of all the driving levers, and $2\times 2\times 8=32$ the product of all the leading levers, and $384 \div 32=12$ the weight w required.

ART. 20.

The same rule holds good in calculating the powers of machines, consisting of wheels whether simple or compound, by counting the radius of the wheels as the levers; and because the diameters and circumferences of circles are proportional; we may take the circumference instead of the radius, and it will be the same. Then again, because the number of cogs in the wheels constitute the circle, we may take the number of cogs and rounds instead of the circle or radius, and the result will be the same.

Let fig. 11, Plate II. represent a water-mill (for grinding grain) double geared:

The sign $+$ more, for addition.
$-$ less, for subtraction.
$\times$ multiplied, for multiplication.
$\div$ divided, for division.
$=$ equal, for equality.

Then, instead of 8 more 4 equal 12, I shall write $8+4=12$. Instead of 12 less 4 equal 8, $12-4=8$. Instead of 6 multiplied by 4 equal 24, $6\times 4=24$. And instead of 24 divided by 3 equal 8, $24\div 3=8$.

Number 8 The water-wheel,
4 The great cog-wheel,
2 The wallower,
3 The counter cog-wheel,
1 The trundle,
2 The mill-stones,

And let the above numbers also represent the radius of the wheels in feet.

Now suppose there be a power of 500lb. on the water-wheel, required what will be the force exerted on the mill-stone, 2 feet from the centre.

Then by the rule, $500 \times 8 \times 2 \times 1 = 8000$, and $4 \times 3 \times 2 = 24$, by which divide 8000, and it quotes 333,33lb. the power or force required, exerted on the mill-stone two feet from its centre, which is the mean circle of a 6 feet stone.—And as the velocities are as the distance from the centre of motion, by 3d law of circular motion, art. 13, therefore, to find the velocity of the mean circle of the stone 2, deduce the following rule, viz.

1st. Multiply the velocity of the water-wheel into the radius or circumference of all the driving wheels, successively, and note the product.

2. Multiply the radius or circumference of all the leading wheels, successively, and note the product; divide the first by the last product, and the quotient will be the answer.

But observe here, that the driving wheels in this rule, are the leading levers in the last rule.

EXAMPLES.

Suppose the velocity of the water-wheel to be 12 feet per second; then by the rule $12 \times 4 \times 3 \times 2 = 288$ and $8 \times 2 \times 1 = 16$ by which divide the first product 288, and it quotes 18 feet per second, the velocity of the stone, 2 feet from its centre.

ART. 21.

POWER DECREASES AS MOTION INCREASES.

It may be proper to observe here, that as the velocity of the stone is increased, the power to move it is decreased, and as its velocity is decreased, the power on it to move it is increased, by 2d general law of mechanical powers. This holds universally true in all engines that can possibly be contrived; which is evident from the 1st law of the lever, viz. the power multiplied into its velocity or distance moved, is equal to the weight multiplied into its velocity or distance moved.

Hence the general rule to compute the power of any engine, simple or compound, art. 17. If you have the moving power, and its velocity or distance moved, given, and the velocity or distance of the weight, then, to find the weight,(which, in mills, is the force to move the stone, &c.) divide that product by the velocity of the weight or mill-stone, &c. and it quotes the weight or force exerted on the stone to move it: But a certain quantity or proportion of this force is lost, in order to obtain a velocity to the stone; which is shewn in art. 29.*

ART. 22.

NO POWER GAINED BY ENLARGING UNDERSHOT WATER-WHEELS.

This seems a proper time to shew the absurdity of the idea of increasing the power of the mill, by enlarging the diameter of the water-wheel, on the principle of lengthening the lever, or by double gearing mills where single gears will do; because the power can neither be increased nor diminished by the help of engines, while the velocity of the body moved is to remain the same.

EXAMPLE.

Suppose we enlarge the diameter of the water-wheel from 8 to 16 feet radius, fig. 11, Plate II. and leave the

* Philosophers have hitherto attributed this loss of power to friction, which is owing to the vis inertia of matter.

other wheels the same; then, to find the velocity of the stone, allowing the velocity of the periphery of the water-wheel to be the same (12 feet per second); by the rule $12 \times 4 \times 3 \times 2 = 288$, and $16 \times 2 \times 1 = 32$, by which divide 288, it quotes 9 feet in a second, for the velocity of the stone.

Then to find the power by the rule for that purpose, art. 20, $500 \times 16 \times 2 \times 1 = 16000$, and $4 \times 3 \times 2 = 24$, by which divide 16000, it quotes 666,66lb. the power. But as velocity as well as power, is necessary in mills, we shall be obliged, in order to restore the velocity, to enlarge the great cog-wheel from 4 to 8 radius.

Then, to find the velocity, $12 \times 8 \times 3 \times 2 = 576$, and $16 \times 2 \times 1 = 32$, by which divide 576, it quotes 18, the velocity as before.

Then to find the power by the rule, art. 20, it will be 333,33 as before.

Therefore no power can be gained, upon the principle of lengthening the lever, by enlarging the water-wheel.

The true advantages that large wheels have over small ones, arises from the width of the buckets bearing but a small proportion to the radius of the wheel; because if the radius of the wheel be 8 feet, and the width of the bucket or float-board but 1 foot, the float takes up 1-8 of the arm, and the water may be said to act fairly upon the end of the arm, and to advantage. But if the radius of the wheel be but 2 feet, and the width of the float 1 foot, part of the water will act on the middle of the arm, and act to disadvantage, as the float takes up half the arm. The large wheel also serves the purpose of a fly-wheel; (art. 30), it likewise keeps a more regular motion, and casts off back water better. See art. 70.

But the expense of these large wheels is to be taken into consideration, and then the builder will find that there is a maximum size, (see art. 44), or a size that will yield him the greatest profit.

ART. 23.

NO POWER GAINED BY DOUBLE GEARING MILLS, BUT SOME LOST.

I might also go on to shew that no power or advantage is to be gained by double gearing mills, upon any other principles than the following, viz.

1. The motion necessary for the stone, can sometimes be obtained without having the trundle too small, because we are obliged to have the pitch of the cogs and rounds, and the size of the spindle, large enough to bear the stress of the power. This pitch of gear, and size of spindle, may bear too great a proportion to the radius of the trundle (as does the size of the float to the radius of the water-wheel, art. 22), and may work hard. Therefore there may be a loss of power on that account; as there can be a loss but no gain, by 3d general law of mechanical powers, art. 15.

2. The mill may be made more convenient for two pair of stones to one water-wheel.*

ART. 24.

OF THE PULLEY.

2. The pulley is a mechanical power well known. One pulley, if it be moveable by the weight, doubles the power, because each rope sustains half the weight.

But if two or more pulleys be joined together in the common way, then the easiest way of computing their power is, to count the number of ropes that join to the lower or moveable block, and so many times is the power increased; because all these ropes have to be shortened, and all run into one rope (called the fall) to which the moving power is applied. If there be 4 ropes the power is increased fourfold.† See plate 1. fig. 10.

* Many and great have been the losses sustained by mill-builders, on account of their not properly understanding these principles. I have often met with great high wheels built, where those of half the size and expense would do better; and double gears, where single would do better, &c. &c.

† In this engine there is great loss of original power, by the great fric-

ART. 25.

OF THE WHEEL AND AXLE.

3. The wheel and axle, fig. 17, is a mechanical power, the same as the lever of the first kind; therefore the power is to the weight, as the diameter of the axle is to the diameter of the wheel; or the power multiplied into the radius of the wheel is equal to the weight multiplied into the radius of the axle,* in an equilibrium of this engine.

ART. 26.

OF THE INCLINED PLANE.

4. The inclined plane is the fourth mechanical power; and in this the power is to the weight, as the height of the plane is to its length. This is of use in rolling heavy bodies, such as barrels, hogsheads, &c. into wheel carriages, &c. and for letting them down again. See plate I. fig. 5. If the height of the plane be half its length, then half the force will roll the body up the plane, that would lift it perpendicularly.

ART. 27.

OF THE WEDGE.

5. The wedge is only an inclined plane. Whence, in the common form of it, the power applied will be to the resistance to be overcome, as the thickness of the wedge is to the length thereof. This is a very great mechanical

tion of the pulleys and ropes in bending, &c. But there is a very great improvement lately discovered, on the pully, which is as follows: Make a system of pullies of such construction, that when those of the upper block all fixed together on one pin will revolve in equal time, and the same in the lower block; which effectually evades all the friction of the sides of the pulleys and ropes passing through the blocks. But as it is almost impossible to proportion the diameters of the pullies to the motion of the ropes so exactly, it will be best to let them have liberty to turn on the pin, so as to stretch all the ropes equally.

* There is but little loss of original power in this engine, because it has but little friction.

power, and may be said to excel all the rest; because with it we can effect, what we cannot with any other in the same time, and I think may be computed in the following manner.

If the wedge be 12 inches long and 2 inches thick, then the power to hold it in equilibrio is as 1 to balance 12 resistance; that is, 12 resistance pressing on each side of the wedge,* and when struck with a mallet, the whole force of the gravity of the mallet, added to the whole force of the agent exerted in the stroke, is communicated to the wedge in the time it continues to move: and this force to produce effect, is as the square of the velocity, with which the mallet strikes, multiplied into its weight; therefore the mallet should not be too large, (see art. 44), because it may be too heavy for the workman's strength, and will meet too much resistance from the air, so that it will lose more by lessening the velocity, than it will gain by its weight. Suppose a mallet of 10lb. strike with 5 velocity, its effective momentum 250; but if it strike with 10 velocity, then its effective momentum is 1000. The effects produced by the strokes will be as 250 to 1000; and all the force of each stroke, except what may be destroyed by the friction of the wedge, is added in the wedge, until the sum of these forces amount to more than the resistance of the body to be split, therefore it must give way; but when the wedge does not move, the whole force is destroyed by the friction. Therefore the less the inclination of the sides of the wedge, the greater resistance we can overcome by it, because it will be easier moved by the stroke.

* Now, if we consider that the one 12 acting on the one side of the wedge represents the re-action of the ground on the underside of the inclined plane, we will then plainly see that the wedge and inclined plane are both one thing; for if this wedge be applied to raise a weight of 12, it will require 2 instead of 1 to drive it under the weight. But if the ground would give way under the wedge as easily, and move the same distance that the weight raises, then the weight would be raised only half the height; consequently, 1 would drive the wedge under the weight, and this yielding of the ground equal to the raising of the weight, will truly represent the yielding of the cleft on each side of the wedge. And this is the true principle of the wedge, notwithstanding so much has been said to prove it to be equal to 2 inclined planes. See Ferguson's Lectures.

ART. 28.

OF THE SCREW.

6. The screw is the last mentioned mechanical power, and is a circular inclined plane (which will appear by wrapping a paper, cut in form of an inclined plane, round a cylinder) and the lever of the first kind combined (the lever being applied to force the weight up in the inclined plane), and is a great mechanical power; its use is both for pressure and raising great weights. The power applied is to the weight it will raise, as the distance through which the weight moves is to the distance through which the power moves; that is, as the distance of the threads of the screw is to the circle the power describes; so is the power to the weight it will raise. If the distance of the thread be half an inch, and the lever be 15 inches radius and the power applied be 10lb. then the power will describe a circle of 94 inches, while the weight raises half an inch; then, as half an inch is to 94 inches, so is 10lb. to 1888lb. the weight the engine would raise with 10lb. power. But this is supposing the screw to have no friction, of which it has a great deal.

Perhaps an improvement might be made on the screw, for some particular uses, by introducing rollers to take off the friction. See art. 33.

ART. 29.

We have hitherto considered the action and effect of these engines, as they would answer to the strictness of mathematical theory, were there no such thing as friction or rubbing of parts upon each other; by which means, philosophers have allowed, that one-third of the effect of the machine is, at a medium, destroyed: which brings us to treat of it next in course.*

* But I think it is evident, that this loss of 1-3 of the original power in producing effects by machines, arises from the vis inertia of the matter that is to be moved. For suppose the machine be an elevator, applied to elevate wheat, Plate II. fig 17, art. 34, it is evident, that if we apply only as much power as will hold the weight of the wheat in the buckets in equilibrio, we will have no motion: then in order to obtain a lively motion, we

ART. 30.

OF THE FLY-WHEEL, AND ITS USE.

Before I dismiss the subject of mechanical powers, I shall take notice of the fly-wheel, the use of which is to regulate the motion of engines, and should be made of cast metal, of a circular form, that it may not meet with much resistance from the air.

Many have taken this wheel for an increaser of power, wheras it is, in reality, a considerable destroyer of it; which appears evident, when we consider that it has no motion of its own, but receives all its motion from the first mover, and, as the friction of the gudgeons and resistance of the air are to be overcome, it cannot be done without some power; yet this wheel is of great use in many cases, viz.

1st. For regulating the power, where it is irregularly applied, such as the treadle or crank moved by foot or hand, as spinning-wheels, tnrning-lathes, flax-mills, or where steam is applied, by a crank, to produce a circular motion.

2d. Where the resistance is irregular, by jerks, &c. such as saw-mills, forges, slitting-mills, powder-mills, &c.

The fly-wheel, by its inertia, regulates the motion; because, if it be very heavy, it will require a great many little shocks or impulses of power to give it a considerable velocity, and it will require as many equal shocks of resistance to destroy said velocity, by axiom 3. art. 1.

While a rolling or slitting mill is running empty, the force of the water is employed in generating velocity to the fly-wheel [a heavy water-wheel will have the same effect], which force, summed up in the fly, will be sufficient to continue the motion, without much abatement, while the sheet is running between the rollers; whereas,

will be obliged to apply a further power, which I expect we will find will be nearly 1-3 of the whole, art. 41; and this 1-3 part of the power will be continually employed in changing the state of the wheat from rest to a lively motion. Besides, it is shewn in art. 31, that the friction of most machines is not more than 1-20 part the weight upon a plane; and by the difference between the diameters of the wheels and gudgeons, is reduced to 1.1000 part of the weight, or the moving power.

had the force of the water been lost while the mill was empty, she would have slackened in motion too much before the sheet got through. This may be the case where water is scarce.

CHAPTER X.

ART. 31.

OF FRICTION.

FROM what I can gather from different authors,* and by my own experiments, I conclude that the doctrine of friction is as follows, and we may say it is subject to the following laws, viz.

Laws of Friction.

1. It is neither increased nor decreased by increasing or decreasing the surfaces of contact of the moving body.†

2. It is in proportion to the weight and velocity, conjointly, of the moving body.‡

* Philosophers treating of friction, seem to agree in telling us, that if a perfectly hard body of any weight could be made perfectly smooth and even, and laid on a horizontal plane, perfectly hard, smooth, and even, that then the least force would move the said weight in any horizontal direction; and that it is the roughness of the best polished and smoothed bodies, that is the whole cause of friction; because the body in being moved, has first to be raised over the prominent parts, which is of the nature of an inclined plane. They also say, in treating of the attraction of cohesion, that if two bodies of the same kind of matter could be made perfectly smooth and even, so that the parts would meet exactly, they would strongly cohere or stick together by attraction; by which it appears that the doctrine of friction is not yet well explained.

† They also say, that it is proved by experiment, that if a square piece of wood or brass, as F, Plate II. fig. 13, four inches wide, and 1 inch thick, be made smooth, and laid on a smooth plane, A B C D, and the weight P hung over a pulley, that it will require the weight P to be nearly 1-3 part of the weight of the body F, to draw it along; and that the same, whether it be on its flat side or edge. This proves law 1st, that friction is not increased by increasing the surface of contact.

‡ It has also been proved by experiment, that if we fix the lever L, to draw the weight F, making o its centre of motion, and by a cord make F fast to the lever at the point 1, and hang the weight Q at the end of the lever over a pulley, and make Q just sufficient to move F, Q will then be found to be 1-7 of P, because it will have to move F but 1 7 of the distance. Then move the cord from 1 to 2, and we find the weight Q must now be doubled equal to 2-7 of P to move F; (the reason is evident from the laws

3. This proportion decreases as the weight and velocity increases, but by what ratio is not determined.*

of the lever) because F is double the distance from the centre of motion that it was at 1, and it will have to move double the distance if the lever, or power Q, move the same distance. This shews that friction is as the distance from the centre of motion; that is, it is as the diameter of the gudgeons, double diameter, double friction; therefore gudgeons ought to be as small as possible, so as to be sufficiently strong to endure the stress of the weight.

* They have also proved by experiment, that if F be a brass plate of 6 ounces, and A B C D a brass plate, both well polished and oiled, then it will require the weight P to be nearly 2 ounces to move F. But if F be loaded with 6, 8, or 10 lb. then a sixth part of that weight will be sufficient to draw it along. This proves that the ratio of the friction to the weight decreases, as the weight increases: the reason of which decrease of proportion I take to be as follows, viz. Great part of the friction arises from the cohesion of the parts, even the grease put on to destroy the cohesion, has a cohesion of its own; and this cohesion of parts or of the grease, will not increase with the weight or velocity. Again, if we allow the friction to be occasioned by the weight of the body having to be raised over the prominent parts of the rubbing surface, it is evident, that when it is raised by being started, that it has not to be raised again; therefore the greater the velocity, the less proportion will this resistance (occasioned by the raising of the body) bear to the velocity.

I have made an experiment similar to that of Plate II. fig. 13, with a flat-sided glass bottle, on a smooth poplar plank, oiled; also on a well polished steel plate oiled, and when loaded with 10 lb. it was drawn by 1 lb. and when loaded with 22 lb. it was drawn by 2 lb. and when loaded with 60 lb. it was drawn by 4 1-2 lbs. which is about 1-13 part: and the motion was greatly accelerated, which gives reason to conclude, that less weight would have continued the motion when once begun.

We may reasonably suppose, that the gudgeons of mills, &c. well polished, running on good stones or brass boxes, &c. and well oiled, have as little friction as the bottle and plank; and as we find that the proportion of friction decreases as the weight increases, we may suppose that in great weights it will not amount to more than 1-20 part of the weight, supposing the gudgeons to be the full size or diameter of the wheels, for so they must be in order to be on the same principles of planes rubbing together. Upon these principles I compute the friction of the gudgeons of a well hung water-wheel, as follows: viz. As the diameter of the wheel is to the diameter of the gudgeons, so is 1-20 part of the weight of the wheel, to the weight that will balance the friction.

EXAMPLE.

Suppose a wheel 15 feet diameter, with gudgeons 3 inches diameter, and weighing 4000 lb. by supposition; then, say as 15 feet is to 3 inches, so is 400 | 20 to 3,3 lb. the weight on the periphery of the wheel that will balance the friction of 4000 lb.: which is less than 1-1000 part of the weight; but note that for the same reasons, that friction does not increase with the velocity in direct proportion, neither will it decrease in direct proportion with the velocity of the rubbing surface of the gudgeon: hence we must conclude again that the friction is more than 1-1000 part. By which it appears, that the friction of the gudgeons, well set on good stones or brass boxes, is not in mills worthy the expense of evading. It bears but a small proportion to the friction or resistance of the air, especially where the velocity is great. See art. 9, and 9th law of falling bodies.

4. It is greatly varied by the smoothness or roughness, hardness or softness, of the surfaces of contact of the moving bodies.

5. A body without motion has no friction; therefore, the less the motion, the less the friction.

ART. 32.

OF REDUCING FRICTION.

To reduce friction, we must, by mechanical contrivances, reduce the motion of the rubbing parts as much as possible; which is done, either by making the gudgeons small and the diameter of wheels large, or by fixing the gudgeons to run on friction-wheels. Thus, let A, Plate II. fig 14, represent the gudgeon of a wheel set to run on the verge of two wheels of cast metal passing each other a little, and the gudgeon laying between them. It is evident, that as A turns, it will turn both friction-wheels; and, if the diameter of gudgeon A is 2 inches, and that of the wheels 12, then the wheels will turn once while A turns 6 times, so that the velocity of the gudgeons C C of the wheels, is to the velocity of the gudgeon A, as 1 is to 6, supposing them to be equal in size; but as there are 4 of them to bear A, they may be but half the diameter, and then their velocity will be to that of A, as 1 is to 12; or A might be set on one wheel, as at B, with supporters to keep it on; and, if friction-wheels are added to friction-wheels, the friction may be reduced to almost nothing by that means.

ART. 33.

LATE INVENTION TO REDUCE FRICTION.

Wheel-carriages, pullies, and such wheels as have large axles in proportion to their diameters, have much friction. There has been a late discovery in England, of applying the principle of the roller to them; which may be so done as almost totally to destroy the friction.

The easiest method possible, of moving heavy bodies horizontally, is the roller.

Let A B, Plate II. fig. 15, represent a body of 100 tons weight (with the under side perfectly smooth and even) set on two rollers, perfectly hard, smooth and round, rolling on the horizontal plane C D, perfectly hard, smooth, and even; it is evident that this body is supported by two lines perfectly perpendicular, and, if globes were used instead of rollers, the least force would move it in any horizontal direction; even a spider's web would be sufficient, giving it time to overcome the vis inertia of the body: But as perfect hardness, smoothness, &c. are not attainable, a little friction will still remain.

This principle is, or may be, applied to wheel-carriages, in the following manner:

Let the outside ring B C D, Plate II. fig 16, represent the box of a carriage-wheel, the inside circle A the axle, the circles a a a a a the rollers round the axle between it and the box, and the inner ring a thin plate for the pivots of the rollers to run in, to keep them at a proper distance from each other. When the wheel turns, the rollers pass round on the axle, and on the inside of the box, and we may say without friction, because there is no rubbing of the parts past one another.*

* To explain this, let us suppose the rollers a a a a a to have cogs, and the shaft A, and box to have cogs also, the rollers gearing into the shaft and into the inside of the box. Now it is evident, that if the box will turn round the axle, it must be without any sliding of parts; (and in fact, the prominent parts of the rollers, axle and box, will act as cogs) then, if the rollers and axle be all of one diameter, they will have an equal number of cogs; and as the diameter of the box will be 3 times the diameter of the rollers, it will have 3 times as many cogs. Now it is evident, that the axle must turn 1 1-3 times round, before the same cogs of the rollers and shaft will meet, that were together when it started; because, in that time the rollers will have moved over 1-3 of the box: therefore the axle must turn 3 3-3 times equal to 4 times round, by the time the box is once measured by the rollers. Then suppose we hold the axle at rest, and turn the box round like a carriage wheel; then, while the box turns 1 1-3 times round the axle, it will cause the rollers to move once round; and while the box or wheel turns round the axle 4 times, the rollers will run round it three times. For suppose we divide the box into 3 parts, B C and D, then beginning to turn the box from B to D, it is evident, that while the roller a b measures once round the axle and returns to the same place, it will also measure the box from B to C, and C will have taken the place of B, and the next revolution of the roller D will take the place of C, and the third revolution B returns to where it was at first, and the box has made 4 revo-

CHAPTER. XI.

ART. 34.

OF MAXIMUMS, OR THE GREATEST EFFECTS OF ANY MACHINE.

THE effect of a machine, is the distance which it moves, or the velocity with which it moves any body to which it is applied to give motion, in a given time; and the weight of the body multiplied into its distance moved, or into its velocity, shews he effect.

The theory published by philosophers, and received and taught as true, for several centuries past, is, that any machine will work with its greatest perfection when it is charged with just 4-9 of the power that would hold it in equilibrio, and then its velocity will be just 1-3 of the greatest velocity of the moving power.

To explain this, they suppose the water-wheel, Plate II. fig. 17, to be of the undershot kind, 16 feet diameter, turned by water issuing from under a 4 feet head, with a gate 1 foot wide, 1 foot high drawn; then the force will be 250lbs. because that is the weight of the column of water above the gate, and its velocity will be 16,2 feet per second, as shall be shewn under the head of Hydraulics; then the wheel will be moved by a power of 250lbs. and if let run empty, will move with a velocity of 16 feet per second; but if we hang the weight W to the axle (of 2 feet diameter) with a rope, and continue to add to it until it stops the wheel, and holds it in equilibrio, the weight will be found to be 2000lbs. by the rule, art. 19; and then the effect of the machine is nothing, because the velocity is nothing: But as we decrease the weight W, the wheel begins to move, and its velocity increases accordingly; and then the product of the weight multiplied into its velocity, will increase until the weight is decreased to 4-9 of 2000=888,7,

lutions, while the rollers have made 3 round the axle, and without any sliding of parts, therefore without friction. I might go on to shew, that if the axle be much larger than the rollers, they will also work without sliding.

which multiplied into its distance moved or velocity, will produce the greatest effect, and the velocity of the wheel then be 1-3 of 16 feet, or 5,33 feet per second. So say those who have treated of it.

This will appear plainer to a young learner, if he will conceive this wheel to be applied to work an elevator, as E, Plate II. fig. 17, to hoist wheat, and suppose that the buckets, when all full, contain 9 pecks, and will hold the wheel in equilibrio, it is evident it will then hoist none, because it has no motion; then, in order to obtain motion, we must lessen the quantity in the buckets, when the wheel will begin to move, and hoist faster and faster until the quantity is decreased to 4-9, or 4 pecks, and then, by the theory, the velocity of the machine will be 1-3 of the greatest velocity, when it will hoist the greatest quantity possible in a given time: for if we lessen the quantity in the buckets below 4 pecks, the quantity hoisted in any given time will be lessened.

This is the theory established, for demonstration of which, see Martin's Philosophy, vol. i. p. 185—187.

ART. 35.

OLD THEORY INVESTIGATED.

In order to investigate this theory, and the better to understand what has been said, let us consider as follows, viz.

1. That the velocity of spouting water, under 4 feet head, is 16 feet per second, nearly.

2. The section or area of the gate drawn, in feet, multiplied by the height of the head in feet, gives the cubic feet in the whole column, which multiplied by 62,5 (the weight of a cubic foot of water) gives the weight or force of the whole column pressing on the wheel.

3. That the radius of the wheel, multiplied by the force, and that product divided by the radius of the axle, gives the weight that will hold the wheel in equilibrio.

4. That the absolute velocity of the wheel, subtracted from the absolute velocity of the water, leaves the rela-

tive velocity with which the water strikes the wheel in motion.

5. That as the radius of the wheel is to the radius of the axle, so is the velocity of the wheel to the velocity of the weight hoisted on the axle.

6. That the effects of spouting fluids are as the squares of their velocities (see art. 45, law 6), but the instant force of striking fluids are as their velocities simply. See art. 8.

7. That the weight hoisted, multiplied into its perpendicular ascent, gives the effect.

8. That the weight of water expended, multiplied into its perpendicular descent, gives the power used per second.

On these principles I have calculated the following scale; first supposing the force of striking fluids to be as the square of their striking or relative velocity, which brings out the maximum agreeably to the old theory, viz.

When the load at equilibrio, is 2000, then the maximum load is 888,7=4-9 of 2000, when the effect is at its greatest, viz. 591,98, as appears in the 6th column, and then the velocity of the wheel is 5,333 feet per second, equal to 1-3 of 16, the velocity of the water, as appears in the 5th line of the scale: but as there is an evident error in the first principle of this theory, by counting the instant force of the water on the wheel to be as the square of its striking velocity, therefore it cannot be true. See art. 41.

I then calculate upon this principle, viz. That the instant force of striking fluids is as their velocity simply, then the load that the machine will carry, with its different velocities, will be as the velocity simply, as appears in the 7th column, and the load, at a maxim, is 1000lb.=½ of 2000, the load at equilibrio, when the velocity of the wheel is 8 feet=½ of 16 the velocity of the water per second; and then the effect is at its greatest, as shewn in the 8th column, viz. 1000, as appears in the 4th line of the scale.

This I call the new theory, (because I found that William Waring had also, about the same time, esta-

blished it, see art. 38) viz. That when any machine is charged with just 1-2 of the load that will hold it in equilibrio, its velocity will be just 1-2 of the natural velocity of the moving power, and then its effect will be at a maximum, or greatest possible.

This appears to be the way by which this great error has been so long overlooked by philosophers, and which has rendered the theory of no use in practice, but led many into expensive errors, thereby bringing great discredit upon philosophy.

For demonstrations of the old theory, see Martin's Phil. vol. i. p. 185—187.

A Scale for determining the Maximum Charge and Velocity of Undershot Mills.

		Velocity of the wheel per second, by supposition	Velocity with which the water strikes the wheel in motion, or relative velocity.	Velocity of the weight ascending.	Weight hoisted, according to the old theory.	Effect, by the old theory.	Weight hoisted, according to new theory.	Effect, by new theory.	Ratio of the power and effect at a maximum, the power being 4000 in each case.
	feet.	feet.	feet.	feet.	lbs.	feet.	lbs.	feet.	
Radius of the wheel - - -	8	16	0	2	0	0			Maximum
Radius of the axle - - -	1	12	4	1,5	125	187,5	500	750	by new
Section of the gate in square feet	1	10	6	1,25	281	351	750	937	theory.
		8	8	1	500	500	1000	1000	4 to 1
Height of the head of water -	4	6	10	,75	781,2	585,9	1250	937	
Velocity of the water per second -	16	5,333	10,666	,666	888,7	591,98	1332	878	10 to 1.47
Weight of the column of water pressing on the wheel	lbs.	5	11	,625	945	590,6	1375	859	Maximum by
	250	4	12	,5	1125	562,5	1500	750	old theory.
The weight that holds the wheel in equilibrio	2000	2	14	,25	1531	382,7	1750	375	
		0	16	0	2000		2000		

ART. 36.

NEW THEORY DOUBTED.

But although that I know the velocity of the wheel, by this new theory, is much nearer practice than the old, (though rather slow) yet I am led to doubt the theory, for the following reasons, viz.

When I consider that there are 16 cubic feet of water, equal 1000lbs. expended in a second, which multiplied by its perpendicular descent, 4 feet, produces the power 4000. The ratio of the power and effect by the old theory is as 10 to 1,47, and by the new as 4 to 1; as appears in the 9th column of the scale; which is a proof that the old theory is a great error, and sufficient cause of doubt that there is yet some error in the new. And as the subject is of the greatest consequence in practical mechanics, therefore I proceed to endeavour to discover a true theory, and will shew my work, in order that if I establish a theory, it may be the easier understood, if right, or detected, if wrong.

Attempts made to discover a new Theory.

In the search, I constructed fig. 18, pl. II. which represents a simple wheel with a rope passing over it and the weight P, of 100lbs. at one end to act by its gravity, as a power to produce effects, by hoisting the weight w at the other end.

This seems to be on the principles of the lever, and overshot wheel; but with this exception, that the quantity of descending matter, acting as power, will still be the same, although the velocity will be accelerated, whereas in overshot wheels, the power on the wheel is inversely, as the velocity of the wheel.

Here we must consider,

1. The perpendicular descent of power P, per second, multiplied into its weight, shews the power.

2. That the weight w when multiplied into its perpendicular ascent gives the effect.

3. That the natural velocity of the falling body P, is 16 feet the first second, and the distance it has to fall 16 feet.

4. That we do suppose that the weight w, or resistance, will occupy its proportional part of the velocity. That is, if w be $= \frac{1}{2}$ P, the velocity with which P will then descend, will be $\frac{1}{2}$ 16=8 feet per second.

5. If w be = P, there can be no velocity, consequently no effect; and if w = o then P will descend 16 feet in a second, but produces no effect; because, the power, although 1600 per second, is applied to hoist nothing.

Upon these principles I have calculated the following scale.

A SCALE

FOR

DETERMINING THE MAXIMUM CHARGE,

AND

VELOCITY OF 100lbs. DESCENDING BY ITS GRAVITY.

Power applied on the wheel.	Natural velocity in feet per second, of the power falling freely.	Weight w hoisted, or the resistance in lbs.	Proportion of the velocity occupied by the resistance or weight w hoisted.	Proportion of the velocity left in motion, which is the velocity of both power and weight.	Effect, which is the weight w multiplied into its ascent per second.	Power, which is the power P, multiplied into its descent per second.	Ratio of the power and effect.	
lbs 100	feet. 16	lb.	feet.	feet.	0	1600	10 : 0	
		1	.16	15.84	15 84	1584	10 : .01	
		10	1.6	14 4	144	1440	10 : 1	
		20	3.2	12.8	256	1280	10 : 2	
		30	4.8	11.2	336	1120	10 : 3	
		40	6.4	9.6	384	960	10 : 4	
		50	.8	8.	400	800	10 : 5	maximum,
		60	9.6	6.4	384	640	10 : 6	by new theo-
		70	11.2	4.8	336	480	10 : 7	ry.
		80	12.8	3.2	256	320	10 : 8	
		90	14.4	1.6	144	160	10 : 9	
		99	15.84	.16	15.8	16	10 : 9.9	
		100	16.	0.	0	0		

By this scale it appears, that when the weight w is $=50=\frac{1}{2}$ P the power; the effect is at a maximum, viz. 400, as appears in the 6th column, when the velocity is half the natural velocity, viz. 8 feet per second; and then the ratio of the power to the effect is as 10 to 5, as appears in the 8th line.

By this scale it appears, that all engines that are moved by one constant power, which is equably accelerated in their velocity (if any such there be) as appears to be the case here, must be charged with weight or resistance equal to half the moving power, in order to produce the greatest effect in a given time; but if time be not regarded, then the greater the charge, so as to leave any velocity, the greater the effect, as appears by the 8th column. So that it appears, that an overshot wheel, if it be made immensely capacious, and to move very slow, may produce effects in the ratio of 9,9 to 10 of the power.

ART. 37.

SCALE OF EXPERIMENTS.

The following scale of actual experiments were made to prove whether the resistance occupies its proportion of the velocity, in order that I might judge whether the foregoing scale was founded on true principles; the experiments were not very accurately performed, but often repeated, and proved always nearly the same. See Plate II. fig. 18.

A SCALE

OF

EXPERIMENTS.

Power applied on the wheel, in pounds	Distance it had to descend, in feet	Weight, in pounds, hoisted the whole distance	Equal parts of time (each being two beats of a watch) in which the weight was hoisted the whole distance	Distance, in feet, that the weight moved in 1 of the equal parts of time, found by dividing 40, the whole distance, by the number of equal parts of time taken up in the ascent	Effect, found by multiplying the weight w into the velocity or distance ascended in one of those parts of time	Power, found by multiplying the weight of P into its descent in one of those parts of time	Ratio of the power and effect	Effect, supposing it to be as the square of the velocity of the weight, found by multiplying the weight into the square of the velocity
7	40	7		0	0			
		6	20	2×6	12	14	10 : 8.5	24
		5	15.5	2.6×5	13	18.2	10 : 7.1	33.8
		4	12	3.33×4	13.32	23.31	10 : 5.7	44.35
		3.5	10	4×3.5	14	28	10 : 5.	maximum new theory.
		3	9	4.44×3	13.32	31.08	10 : 4.2	59.14
		2	6.5	6×2	12	42	10 : 2.8	72 maximum.
		1	6	6.6×1	6.6	46.2	10 : 1.4	33.56
		0	5	8	0	56		

By this scale it appears, that when the power P falls freely without any load, it descends 40 feet in five equal parts of time, but, when charged with 3,5lbs.$=\frac{1}{2}$P, which was 7lbs. it then took up 10 of those parts of time to descend the same distance; which seems to shew, that the charge occupies its proportional part of the whole velocity, which was wanted to be known, and the maximum appears as in the last scale.* It also shews, that the effect is not as the weight multiplied into the square of its ascending velocity, this being the measure of the effect that would be produced by the stroke on a non-elastic body.

This experiment partly confirmed me in what I have called the New Theory; but still doubting, and after I had formed the foregoing tables, I called on the late ingenious and worthy friend, William Waring, teacher in the Friends' Academy, Philadelphia, for his assistance. He told me he had discovered the error in the old theory and corrected it in a paper which he had laid before the Philosophical Society of Philadelphia, wherein he had shewn that the velocity of the undershot water-wheel, to produce a maximum effect, must be just one half the velocity of the water.

ART. 38.

WILLIAM WARING'S THEORY.

The following are extracts from the above mentioned paper, published in the third volume of the Transactions of the American Philosophical Society, held at Philadelphia, p. 144.

After his learned and modest introduction, in which he shews the necessity of correcting so great an error as the old theory, he begins with these words, viz.

" But to come to the point, I would just premise these

* Since writing the above, I have seen Atwood's Treatise on Motion, wherein he gives a set of accurate experiments, to prove (beyond doubt) that the conclusion I have drawn is right, viz. That the charge occupies its proportional part of the whole velocity. See the American Encyclopedia, vol. x. p. 786.

DEFINITIONS.

If a stream of water impinge against a wheel in motion, there are three different velocities to be considered appertaining thereto, viz.

First, The absolute velocity of the water.

Second, The absolute velocity of the wheel.

Third, the relative velocity of the water to that of the wheel; *i. e.* the difference of the absolute velocities, or the velocity with which the water overtakes or strikes the wheel.

Now the mistake consists in supposing the momentum, or force of the water against the wheel, to be in the duplicate ratio of the relative velocity; Whereas,

PROP. I.

The force of an invariable stream, impinging against a mill-wheel in motion, is in the simple proportion of the relative velocity.

For, if the relative velocity of a fluid against a single plane, be varied, either by the motion of the plane or of the fluid from a given aperture, or both, then the number or particles acting on the plane, in a given time, and likewise the momentum of each particle being respectively as the relative velocity, the force, on both these accounts, must be in the duplicate ratio of the relative velocity, agreeable to the common theory, with respect to this single plane; but the number of these planes or parts of the wheel, acted on in a given time, will be as the velocity of the wheel, or inversely as the relative velocity; therefore the moving force of the wheel must be as the simple ratio of the relative velocity. Q. E. D.

Or the proposition is manifest from this consideration, that while the stream is invariable, whatever be the velocity of the wheel, the same number of particles, or quantity of the fluid, must strike it somewhere or other in a given time; consequently, the variation of the force is only on account of the varied impingent velocity of the same body, occasioned by a change of motion in the wheel; that is, the momentum is as the relative velocity.

Now this true principle, substituted for the erroneous one in use, will bring the theory to agree remarkably with the notable experiments of the ingenious Smeaton, published in the Philosophical Transactions of the Royal Society of London, for the year 1751, vol. 51; for which the honorary annual medal was adjudged by the society, and presented to the author by their president.

An instance or two of the importance of this correction may be adduced, as follows:

PROP. II.

The velocity of a wheel, moved by the impact of a stream, must be half the velocity of the fluid, to produce the greatest effect possible.

$\left\{\begin{array}{l} V=\text{the velocity, } M=\text{the momentum, of the fluid.} \\ v=\text{the velocity, } P=\text{the power, of the wheel.}\end{array}\right.$

Then $V-v$=their relative velocity, by definition 3d.

And, as $V:V-v::M:\frac{M}{V}\times\overline{V-v}=P$, (Prop. 1.) which $\times v=P$, $v=\frac{M}{V}\times\overline{Vv-v^2}$=a maximum; hence $Vv-v^2=$ a maximum and its fluxion (v being a variable quantity) $=V\dot{v}-2v\dot{v}=0$; therefore$=\frac{1}{2}V$; that is, the velocity of the wheel=half that of the fluid, at the place of impact, when the effect is a maximum. Q. E. D.

The usual theory gives $v=\frac{1}{3}V$, where the error is not less than one sixth of the true velocity.

Wm. WARING.

Philadelphia, 7*th* }
9*th mo.* 1790. }

Note, I omit quoting prop. III. as it is in algebra, and refers to a figure, because I am not writing so particularly to men of science, as to practical mechanics.

ART. 39.

Extract from a further paper, read in the Philosophical Society, April 5th, 1793.

"Since the Philosophical Society were pleased to favour my crude observations on the theory of mills, with a publication in their transactions, I am apprehensive some part thereof may be misapplied, it being therein demonstrated, that 'the force of an invariable stream, impinging against a mill-wheel in motion, is in the simple direct ratio of the relative velocity.' Some may suppose that the effect produced, should be in the same proportion, and either fall into an error, or finding by experiment, the effect to be as the square of the velocity, conclude the new theory to be not well founded; I therefore wish there had been a little added, to prevent such misapplication, before the Society had been troubled with the reading of my paper on that subject: perhaps something like the following.

The maximum effect of an undershot wheel, produced by a given quantity of water, in a given time, is in the duplicate ratio, of the velocity of the water: for the effect must be as the impetus acting on the wheel, multiplied into the velocity thereof: but this impetus is demonstrated to be simply as the relative velocity, Prop. I. and the velocity of the wheel, producing a maximum, being half of the water by Prop. II. is likewise as the velocity of the water; hence the power acting on the wheel, multiplied into the velocity of the wheel, or the effect produced, must be in the duplicate ratio of the velocity of the water. Q. E. D.

COROL. Hence the effect of a given quantity of water, in a given time, will be as the height of the head, because this height is as the square of the velocity. This also agrees with experiment.

If the force, acting on the wheel, were in duplicate ratio of the water's velocity, as usually asserted, then the effect would be as the cube thereof, when the quantity of water and time are given, which is contrary to the result of experiment."

ART. 40.

WARING'S THEORY DOUBTED.

From the time I first called on William Waring, until I read his publication on the subject, (after his death) I had rested partly satisfied, with the new theory, as I have called it, with respect to the velocity of the wheel, at least; but finding that he had not determined the charge, as well as the velocity, by which we might have compared the ratio of the power and the effect produced, and that he had assigned reasons somewhat different for the error; and having found the motion to be rather too slow to agree with practice, I began to suspect the whole, and resumed the search for a true theory, thinking that perhaps no person had ever yet considered every thing that affects the calculation, I therefore premised the following

POSTULATES.

1. A given quantity of perfect, elastic or solid matter, impinging on a fixed obstacle, its effective force is as the squares of its different velocities, although its instant force may be as its velocities simply, by annotation, art. 8.*

2. An equal quantity of elastic matter, impinging on a fixed obstacle with a double velocity, produces a quadruple effect, art. 8; i. e. their effects are as the squares of their velocities. Consequently,

3. A double quantity of said matter, impinging with a double velocity, produces an octuble effect, or their effects are as the cubes of their velocities, art. 47 and 67.

4. If the impinging matter be non-elastic, such as fluids, then the instant force will be but half in each case, but the ratio will be the same in each case.

5. A double velocity, through a given aperture, gives a double quantity to strike the obstacle or wheel, therefore the effects, by postulate 3, will be as the cubes of the velocity. See art. 47.

* Because the distance it will recede after the stroke through any resisting medium, will be as the squares of its impinging velocities.

6. But a double relative velocity cannot increase the quantity that is to act on the wheel, therefore the effect can only be as the square of the velocity, by postulate 2.

7. Although the instant force and effects of striking fluids on fixt obstacles, are only as their simple velocities, yet their effects, on moving wheels, are as the squares of their velocities; because, 1, a double striking velocity gives a double instant force, which bears a double load on the wheel; and 2, a double velocity moves the load a double distance in an equal time, and a double load moved a double distance, is a quadruple effect.

ART. 41.

SEARCH FOR A TRUE THEORY, COMMENCED ON A NEW PLAN.

It appears that we have applied wrong principles in our search after a true theory of the maximum velocity and load of undershot water-wheels, or other engines moved by a constant power, that does not increase or decrease in quantity on the engine, as on an overshot water-wheel, as the velocity varies.

Let us suppose water to issue from under a head of 16 feet, on an undershot water-wheel: then, if the wheel moves freely with the water, its velocity will be 32,4 feet per second, but will bear no load.

Again, suppose we load it, so as to reduce its motion to be equal the velocity of water spouting from under 15 feet; it appears evident that the load will then be just equal to that 1 foot of the head, the velocity of which is checked; and this load multiplied into the velocity of the wheel, viz. $31{,}34 \times 1 = 31{,}34$ for the effect.

This appears to be the true principle, from which we must seek the maximum velocity and load, for such engines as are moved by one constant power; and on this principle I have calculated the following scale.

A SCALE

FOR DETERMINING THE

TRUE MAXIMUM VELOCITY AND LOAD

FOR

UNDERSHOT WHEELS.

Total head of water in action.	Head of water left unbalanced to give motion to the wheel.	Velocity of the wheel in feet per second, being equal the velocity of the water from under the head left unbalanced.	Load of the wheel, being equal that part of the total head, the motion of which is checked.	Effect per second, being the velocity of the wheel, multiplied by the load.	
feet	feet.	feet.			
16	16	32.4	0	0	
	15	31.34	1	31 34	
	14	30.2	2.	60 4	
	12	28.	4.	112	
	10	25.54	6	153.24	
	8	22 8	8	182.4	
	7	21 43	9	192.87	
	6	19.84	10	198.4	
	5.66	19.27	10.33	198.95	
	5.33	18.71	10.66	199 44	Maximum motion and load.
	5	18.	11	198	
	4	16.2	12	194 4	
	3	14.	13	172	
	2	11.4	14	159.6	
	1	8 1	15	120.	
	0	0	16	0	

In this scale let us suppose the aperture of the gate to be a square foot; then the greatest load that will balance the head, will be 16 cubic feet of water, and the different loads will be shewn in cubic feet of water.

And then it appears, by this scale, that when the wheel is loaded with 10,66 cubic feet of water, just 2-3 of the greatest load, its velocity will be 18,71 feet per second, just ,577 parts of the velocity of the water, and the effect produced is at a maximum, or the greatest possible, viz. 199,44.

To make this more plain, let us suppose A B, plate II, fig. 19, to be a fall of water 16 feet, which we wish to apply to produce the greatest effect possible, by hoisting water on its side opposite to the power applied; first, on the undershot principle, where the water acts by its impulse only. Now let us suppose the water to strike the wheel at I, then, if we let the wheel move freely without any load, it will move with the velocity of the water, viz. 32,4 feet per second, but will produce no effect, if the water issue at C; although there be 32,4 cubic feet of water expended, under 16 feet perpendicular descent. Let the weight of a cubic foot of water be represented by unity or 1, for ease in counting; then $32{,}4\times16$ will show the power expended, per second, viz. 518,4; and the water it hoists multiplied into its perpendicular ascent, or height hoisted, will shew the effect. Then, in order to obtain effect from the power, we load the wheel; the simplest way of doing which, is, to cause the tube of water C D to act on the back of the bucket at I; then, if CD be equal to AB, the wheel will be held in equilibrio; this is the greatest load, and the whole of the fall AB is balanced, and no part left to give the wheel velocity; therefore the effect=0. But if we make CD=12 feet of AB, then from 4 to A=4 feet, is left unbalanced, to give velocity to the wheel, which is now loaded with 12 feet, and exactly balanced by 12 on the other side, and perfectly free to move either way by the least force applied: Therefore it is evident, that the whole pressure or force of 4 feet of AB will act to give velocity to the wheel, and, as there is no resistance to oppose the pressure of these 4 feet, the velocity will be

the same that water will spout from under 4 feet head, viz. 16,2 feet per second, which is shewn by the horizontal line 4=16,2, and the perpendicular line 12=12 represents the load of the wheel; the rectangle or product of these two lines, form a parallelogram, the area of which is a true representation of the effect, viz. the load 12 multiplied into 16,2 the distance it moves per second =194,4, the effect. In like manner we may try the effect of different loads; the less the load, the greater will be the velocity. The horizontal lines all shew the velocity of the wheel, produced by the respective heads left unbalanced, and the perpendicular lines shew the load on the wheel; and we find, that when the load is 10,66=$\frac{2}{3}$16, the load at equilibrio, the velocity of the wheel will be 18,71 feet per second, which is $\frac{577}{1000}$ parts, or a little less than 6 tenths, or $\frac{2}{3}$ the velocity of the water, and the effect is 199,44 the maximum or greatest possible; and if the aperture of the gate be 1 foot, the quantity will be 18,71 cubic feet per second. The power being 18,71 cubic feet expended per second, multiplied by 16 feet the perpendicular descent, produces 299,36, and the ratio of the power and effect being 10 to 6$\frac{8}{10}$, or as 3 : 2; but this is supposing none of the force lost by non-elasticity.

This may appear plainer, if we suppose the water to descend the tube A B, and, by its pressure, to raise the water in the tube C D; now it is evident, that if we raise the water to D, we have no velocity, therefore effect=0. Then again, if we open the gate at C, we have 32,4 feet per second velocity, but because we do not hoist the water any distance, effect=0. Therefore, the maximum is somewhere between C and D. Then suppose we open gates of 1 foot area, at different heights, the velocity will shew the quantity of cubic feet raised; which multiplied by the perpendicular height of the gate from C, or height raised, gives the effect as before, and the maximum as before. But here we must consider, that in both these cases the water acts as a perfect definite quantity, which will produce effects equal to elastic bodies, or equal to its gravity (see art. 59), which is impracticable in practice: Whereas, when it acts by percussion only, it communicates only half of its original

force, on account of its non-elasticity, the other half being spent in splashing about (see art. 8); therefore the true effect will be $\frac{38}{100}$ (a little more than 1-3) of the moving power; because near 1-3 is lost to obtain velocity, and half of the remaining 2-3 is lost by non-elasticity. These are the reasons, why the effects produced by an undershot wheel is only half of that produced by an overshot wheel, the perpendicular descent and quantity of water being equal. And this agrees with Smeaton's experiments (see art. 68); but if we suppose the velocity of the wheel to be one-third that of the water=10,8, and the load to be 4-9 of 16, the greatest load at equilibrio; which is=7,111, as by old theory, then the effect will be 10,8×4,9 of 16=76,79 for the effect, which is quite too little, the moving power being 32,4 cubic feet of water, multiplied by 16 feet descent=518,4, the effect by this theory being less than $\frac{15}{100}$ of the power, about half equal to the effect by experiment, which effect is set on the outside of the dotted circle in the fig. (19). The dotted lines join the corner of the parallelograms, formed by the lines that represent the loads and velocities, in each experiment or supposition, the areas of which truly represent the effect, and the dotted line A a d x, meeting the perpendicular line x E in the point x, forming the parallelogram ABCx, truly represents the power=518,4.

Again, if we suppose the wheel to move with half the velocity of the water, viz. 16,2 feet per second, and be loaded with half the greatest load=8, according to Waring's theory, then the effect will be 16,2×8=129,6 for the effect, about $\frac{23}{100}$ of the power, which is still less than by experiment. All this seems to confirm the maximum brought out on the new principles.

But, if we suppose, according to the new principle, that, when the wheel moves with the velocity of 16,2 feet per second, which is the velocity of a 4 feet head, that it will then bear as a load the remaining 12 feet, then the effect will be 16,2×12=194,4, which nearly agrees with practice: but as most mills in practice move faster, rather than slower, than what I call the true maximum, shews it to be nearest the truth, the true maximum velocity being ,577 of the velocity of the

water, and the mills in practice moving with 2-3, and generally quicker.*

This scale also establishes a true maximum charge for an overshot wheel, when the case is such, that the power or quantity of water on the wheel at once, is always the same, even although the velocity vary, which would be the case, if the buckets were kept always full: for, suppose the water to be shot into the wheel at a, and by its gravity to raise the whole water again on the opposite side; then, as soon as the water rises in the wheel to d, it is evident that the wheel will stop, and effect=0; therefore we must let the water out of the wheel, before it rises to d, which will be in effect to lose part of the power to obtain velocity. If the buckets both descending and ascending, carry a column of water 1 foot square, then the velocity of the wheel will shew the quantity hoisted as before, which, multiplied by the perpendicular ascent, shews the effect, and the quantity expended, multiplied by the perpendicular descent shows the power; and we find, that when the wheel is loaded with 2-3 of the power, the effect will be at a maximum, *i. e.* the whole of the water is hoisted, 2-3 of its whole descent, or 2-3 of the water the whole of the descent, therefore the ratio of the power to the effect is as 3 to 2, double to the effect of an undershot wheel: but this is, supposing the quantity in

* The reason why the wheel bears so great a load at a maximum, appears to be as follows, viz.

A 16 feet head of water over a gate of 1 foot, issues 32,4 cubic feet of water in a second, to strike the wheel in the same time, that a heavy body will take up in falling through the height of the head. Now if 16 cubic feet of elastic matter, was to fall 16 feet, and strike an elastic plane, it would rise by the force of the stroke, to the height from whence it fell; or, in other words, it will have force sufficient, to bear a load of 16 cubic feet.

Again, if 32 cubic feet of non elastic matter, moving with the same velocity, (with which the 16 feet of elastic matter struck the plane) strike a wheel in the same time, although it communicate only half the force, that gave it motion; yet, because there is a double quantity striking in the same time, the effects will be equal, that is, it will bear a load of 16 cubic feet, or the whole column to hold it in equilibrio.

Again, to check the whole velocity, requires the whole column, that produces the velocity, consequently, to check any part of the velocity, will require such a part of the column that produces the part checked; and we find by art. 41, that, to check the velocity of the wheel, to be ,577 of the velocity of the water, it requires 2-3 of the whole column, and this is the maximum load When the velocity of the wheel, is multiplied by 2-3 of the column, it produces the effect, which will be to the power, as 38 to 100; or as 3,8 to 10, somewhat more than 1-3, and the friction and resistance of the air may reduce it to 1-3.

the buckets to be always the same; whereas, in overshot wheels, the quantity in the buckets is inversely as the velocity of the wheel, *i. e.* the slower the motion of the wheel, the greater the quantity in the buckets, and the greater the velocity the less the quantity: but, again, as we are obliged to let the overshot wheel move with a considerable velocity, in order to obtain a steady, regular motion to the mill, we will find this charge to be always nearly right; hence I deduce the following theory.

ART. 42.

THEORY.

A TRUE THEORY DEDUCED.

This scale seems to have shewn,

1. That when an undershot mill moves with ,577 or nearly ,6 of the velocity of the water, it will then bear a charge, equal to 2-3 of the load, that will hold the wheel in equilibrio, and then the effect will be at a maximum. The ratio of the power to the effect will be as 3 to 1, nearly.

2. That when an overshot wheel is charged with 2-3 of the weight of the water acting upon the wheel, then the effect will be at a maximum, *i. e.* the greatest effect, that can be produced by said power in a given time, and the ratio of the power to the effect will be as 3 to 2, nearly.

3. That 1-3 of the power is necessarily lost to obtain velocity, or to overcome the vis inertia of the matter, and this will hold true with all machinery that requires velocity as well as power. This I believe to be the true theory of water-mills, for the following reasons, viz.

1. The theory is deduced from original reasoning, without depending much on calculation.

2. It agrees better than any other theory, with the ingenious Smeaton's experiments.

3. It agrees best with real practice, from the best of my information.

Yet I do not wish any person to receive it implicitly, without first informing himself, whether it be well founded, and agrees with practice: for this reason I have quoted said Smeaton's experiments at full length, in this work, that the reader may compare them with the theory.

TRUE THEOREM FOR FINDING THE MAXIMUM CHARGE FOR UNDERSHOT WHEELS

As the square of the velocity of the water or wheel empty, is to the height of the head, or pressure, which produced that velocity, so is the square of the velocity of the wheel, loaded to the head, pressure, or force, which will produce that velocity; and this pressure, deducted from the whole pressure or force, will leave the load moved by the wheel, on its periphery or verge, which load, multiplied by the velocity of the wheel, shews the effect.

PROBLEM.

Let $V=32{,}4$, the velocity of the water or wheel,

$P=16$, the pressure, force, or load, at equilibrio,

$v=$the velocity of the wheel, supposed to be 16,2 feet per second,

$p=$the pressure, force or head, to produce said velocity,

$l=$the load on the wheel,

Then to find l, the load, we must first find p;

Then, by

Theorem $VV:P::vv:p$,

And $P-p=l$

$$VVp=vvP$$

$$p=\frac{vvP}{VV}=4$$

$$l=P-p=12, \text{ the load.}$$

Which, in words at length, is, the square of the velocity of the wheel, multiplied by the whole force, pressure, or head of the water, and divided by the square of the velocity of the water, quotes the pressure, force, or head of water, that is left unbalanced by the load, to produce the velocity of the wheel, which pressure, force or head,

subtracted from the whole pressure, force or head, leaves the load that is on the wheel.

ART. 43.

Theorem for finding the velocity of the wheel, when we have the velocity of the water, Load at equilibrio, and Load on the wheel given.

As the square root of the whole pressure, force or load at equilibrio, is to the velocity of the water, so is the square root of the difference, between the load on the wheel, and the load at equilibrio, to the velocity of the wheel.

PROBLEM.

Let V=velocity of the water=32,4,
P=pressure, force, head, or load at equilibrio=16,
l=the load on the wheel, suppose 12,
v=velocity of the wheel,
Then by the
Theorem $\sqrt{P} : V :: \sqrt{P-l} : v$
And $\sqrt{P} \times v = V\sqrt{P-l}$

$$v=\frac{V\sqrt{P-l}}{\sqrt{P}}=-=16,2.$$ The velocity of the wheel.

That is, in words at length, the velocity of the water 32,4, multiplied by the square root of the difference, between the load on the wheel, 12, and the load at equilibrio 16=2=64,8, divided by the square root of the load at equilibrio, quotes 16,2, the velocity of the wheel.

Now, if we seek for the maximum, by either of these theorems, it will be found as in the scale, fig. 19.

Perhaps here may now appear the true cause of the error of the old theory, art. 35, by supposing the load on the wheel, to be as the square of the relative velocity, of the water and wheel.

And of the error of what I have called the new theory, by supposing the load to be in the simple ratio of the relative or striking velocity of the water, art. 38; whereas it is to be found by neither of these proportions.

Neither the old nor new theories agree with practice; therefore we may suspect they are founded on error.

But if what I call the true theory, should continue to agree with practice, the practitioner need not care on what it is founded.

ART. 44.

Of the Maximum velocity for Overshot Wheels, or those that are moved by the weight of the Water.

Before I dismiss the subject of maximums, I think it best to consider, whether this doctrine will apply to the motion of the overshot wheels. It seems to be the general opinion of those, who consider the matter, that it will not; but, that the slower the wheel moves, provided it be capacious enough to hold all the water, without losing any until it be delivered at the bottom of the wheel, the greater will be the effect, which appears to be the case in theory (see art. 36); but how far this theory will hold good in practice is to be considered. Having met with the ingenious James Smeaton's experiments, where he shews, that, when the circumference of his little wheel, of 24 inches diameter, (head 6 inches) moved with about 3,1 feet per second (although the greatest effect was diminished about $\frac{1}{20}$ of the whole) he obtained the best effect, with a steady, regular motion. Hence he concludes about three feet to be the best velocity for the circumference of overshot mills. See art. 68. I undertook to compare this theory of his, with the best mills in practice, and, finding that those of about 17 feet diameter, generally moved about 9 feet per second, being treble the velocity assigned by Smeaton, I began to doubt the theory, which led me to inquire into the principle that moves an overshot wheel, and this I

found to be a body descending by its gravity, and subject to all the laws of falling bodies, (art. 9) or bodies of descending inclined planes, and curved surfaces (art. 10, 11,) the motion being equably accelerated in the whole of its descent, its velocity being as the square root of the distance descended through, and the diameter of the wheel was the distance the water descended through. From thence I concluded, that the velocity of the circumferance of the overshot wheels, was as the square root of their diameters, and of the distance the water has to descend, if it be a breast or pitch-back wheel: then, taking Smeaton's experiments, with his wheel of 2 feet diameter, for a foundation, I say, As the square root of the diameter of Smeaton's wheel, is to its maximum velocity, so is the square root of the diameter of any other wheel, to its maximum velocity. Upon these principles I have calculated the following table; and, having compared it with at least 50 mills in practice, found it to agree so nearly with all the best constructed ones, that I have reason to believe it is founded on true principles.

If an overshot wheel moves freely without resistance, it will require a mean velocity, between that of the water coming on the wheel, and the greatest velocity it would acquire, by falling freely through its whole descent: therefore this mean velocity will be greater, than the velocity of the water coming on the wheel; consequently the backs of the buckets will overtake the water, and drive a great part of it out of the wheel. But, the velocity of the water being accelerated by its gravity, overtakes the wheel, perhaps half way down, and presses on the buckets, until it leaves the wheel: therefore the water presses harder upon the buckets in the lower, than in the upper quarter of the wheel. Hence appears the reason why some wheels cast their water, which is always the case, when the head is not sufficient to give it velocity enough to enter the buckets. But this depends also much on the position of the buckets, and direction of the shute into them. It, however, appears evident that the head of water above the wheel, should be nicely adjusted, to suit the velocity of

the wheel. Here we may consider, that the head above the wheel acts by percussion, or on the same principles with the undershot wheel, and, as we have shewn (art. 41.) that the undershot wheel should move with nearly 2-3 of the velocity of the water, it appears, that we should allow a head over the wheel, that will give such velocity to the water, as will be to that of the wheel as 3 to 2. Thus the whole descent of the water of a mill-seat should be nicely divided, between head and fall, to suit each other, in order to obtain the best effect, and a steady-moving mill. First find the velocity that the wheel will move with, by the weight of the water, for any diameter you may suppose you will take for the wheel, and divide said velocity into two parts; then try if your head is such, as will cause the water to come on with a velocity of 3 such parts, making due allowances for the friction of the water, according to the aperture. See art. 55. Then if the buckets and direction of the shute be right, the wheel will receive the water well, and move to the best advantage, keeping a steady, regular motion when at work, loaded or charged with a resistance equal to 2-3 of its power, (art. 41, 42.)

A TABLE
OF
VELOCITIES OF THE CIRCUMFERENCE
OF
OVERSHOT WHEELS,

Suitable to their Diameters, or rather to the Fall, after the Water strikes the Wheel; and of the head of Water above the Wheel, suitable to said Velocities, also of the Number of Revolutions the Wheel will perform in a Minute, when rightly charged.

Diameter of the wheel in feet.	Velocity of its circumference in feet and parts per second.	Head of water above the wheel to give velocity as 3 to 2 of the wheel, in feet and parts.	Additional head to overcome the friction of the aperture, by conjecture only.	Total head of water.	No. of revolutions of the wheel per minute.
2	3,1				
3	3,78				
4	4,38				
5	4,88				
6	5,36				
7	5, 8				
8	6,19				
9	6,57	1,41	,1	1,51	14,3
10	6,92	1,64	,1	1,74	13,
11	7,24	1,84	,1	1,94	12,6
12	7,57	2,	,2	2,2	12,
13	7,86	2,17	,3	2,47	11,54
14	8,19	2,34	,4	2,74	11,17
15	8,47	2,49	,5	2,99	10,78
16	8,76	2,68	,6	3,28	10,4
17	9,	2, 8	,7	3,5	10,1
18	9,28	3,	,8	3,8	9,8
19	9, 5	3,13	,9	4,03	9,54
20	9,78	3,34	1,	4,34	9,3
21	10,	3,49	1,05	4,54	9,1
22	10,28	3,76	1,1	4,86	8,9
23	10, 5	3,84	1,15	4,99	8,7
24	10, 7	4,97	1,2	5,27	8,5
25	10,95	4, 2	1,25	5,45	8,3
26	11,16	4,27	1,3	5,57	8,19
27	11,36	4,42	1,35	5,77	8,03
28	11,54	4,56	3,4	5,96	7,93
29	11,78	4, 7	1,45	6,15	7,75
30	11,99	4, 9	1,5	6,4	7,63

This doctrine of maximums is very interesting, and is to be met with in many occurences through life.

1. It has been shewn, that there is a maximum load and velocity for all engines, to suit the power and velocity of the moving power.

2. There is also a maximum size, velocity, and feed for mill-stones, to suit the power; and velocity for rolling screens, and bolting-reels, by which the greatest work can be done in the best manner, in a given time.

3. A maximum degree of perfection and closeness, with which grain is to be manufactured into flour, so as to yield the greatest profit by the mill in a day or week, and this maximum is continually changing with the prices in the market, so that what would be the greatest profit at one time, will sink money at another. See art. 113.

4. A maximum weight for mallets, axes, sledges, &c. according to the strength of those that use them.

A true attention to the principles of maximums, will prevent us from running into many errors.

CHAPTER XII.

HYDRAULICS.

UNDER the head of Hydraulics we shall only consider such parts of this science, as immediately relate to our purpose, viz. such as may lead to the better understanding of the principles and powers of water, acting on mill-wheels, and conveying water to them.

ART. 45.

OF SPOUTING FLUIDS.

Spouting fluids observe the following laws:

1. Their velocities and powers, under equal pressures, or equal perpendicular heights, and equal apertures, are equal in all cases.*

2. Their velocities under different pressures or perpendicular heights, are as the square roots of those pressures or heights; and their perpendicular heights or pressures, are as the squares of their velocities.†

* It makes no difference whether the water stands perpendicular above the aperture, or incliningly (see plate III, fig. 22) providing the perpendicular height be the same; or whether the quantity be great or small, providing it be sufficient to keep up the fluid to the same height.

† This law is similar to the 4th law of falling bodies, their velocities being as the square root of their spaces passed through; and by experiment it is known, that water will spout from under a 4 feet head, 16,2 feet per second, and from under a 16 feet head, 32,4 feet per second, and from under a 16 feet head, 32,4 feet per second, which is only double to that of a 4 feet head, although there be a quadruple pressure. Therefore by this law we can find the velocity of water spouting from under any given head; for as the square root of 4 equal 2 is to 16,2 its velocity, so is the square root of 16 equal 4, to 32,4 squared, to 16 its head: by which ratio we can find the head that will produce any velocity.

3. Their quantities expended through equal apertures, in equal times, under unequal pressures, are as their velocities simply.*

4. Their pressures or heights being the same, their effects are as their quantities expended.†

5. Their quantities expended being the same, their effects are as their pressure, or height of their head directly.‡

6. Their instant forces with equal apertures, are as the squares of their velocities, or as the height of their heads directly.

7. Their effects are as their quantities, multiplied into the squares of their velocities.§

* It is evident that a double velocity will vent a double quantity.

† If the pressure be equal, the velocity must be equal; and it is evident, that double quantity, with equal velocity will produce a double effect.

‡ That is, if we suppose 16 cubic feet of water to issue from under a 4 feet head in a second, and an equal quantity to issue in the same time from under 16 feet head, then their effects will be as 4 to 16. But we must note, that the aperture in the last case must be only half of that in the first, as the velocity will be double.

§ This is evident from this consideration, viz. that a quadruple impulse is required to produce a double velocity, by law 2nd, where the velocities are as the square roots of their heads: therefore their effects must be as the squares of their velocities.

ART. 46.

DEMONSTRATION.

Let A F, (plate III, fig. 26) represent a head of water 16 feet high, and suppose it divided into 4 different heads of 4 feet each, as B C D E; then suppose we draw a gate of 1 foot square at each head successively, always sinking the water in the head, so that it will be but 4 feet above the centre of the gate in each case.

Now it is known that the velocity under a four feet head, is 16,2 feet per second; say 16 feet to avoid fractions, which will issue 16 cubic feet of water per second, and for sake of round numbers, let unity or 1 represent the quantity of a cubic foot of water; then, by the 7th law the effect will be as the quantity multiplied by the square of the velocity; that is, 16 multiplied by 16 is equal to 256, which multiplied by 16, the quantity is equal to 4096, the effect of each 4 feet head; and 4096 multiplied by 4 is equal to 16384, for the sum of effects, of all the 4 feet heads.

Then as the velocity under a 16 feet head is 32,4 feet, say 32 to avoid fractions; the gate must be drawn to only half the size, to vend the 16 cubic feet of water per second as before (because the velocity is double); then, to find the effect, 32 multiplied by 32, is equal to 1024; which multiplied by 16, the quantity, gives the effect, 16384, equal the sum of all the 4 feet

head which agrees with the practice and experience of the best teachers. But if their effects were as their velocities simply, then the effect of each 4 feet head would be, 16 multiplied by 16, equal to 256; which, multiplied by 4, is equal to 1024, for the sum of the effects of all the 4 feet heads; and 16 multiplied by 32 equal to 512, for the effect of the 16 feet head, which is only half of the effect of the same head when divided into 4 parts; which is contrary to both experiment and reason.

Again, let us suppose the body A of quantity 16, to be perfectly elastic, to fall 16 feet and strike F, a perfect elastic plane, it will (by laws of falling bodies) strike with a velocity of 32 feet per second, and rise 16 feet to A again.

But if it fall only to B, 4 feet, it will strike with 16 feet per second, and rise 4 feet to A again. Here the effect of the 16 feet fall is 4 times the effect of the 4 feet fall, because the body rises 4 times the height.

But if we count the effective momentum of their strokes to be as their velocities simply, then 16 multiplied by 32 is equal to 512, the momentum of the 16 feet fall; and 16 multiplied by 16 is equal to 256; which, multiplied by 4, is equal to 1024, for the sum of the momentums of the strokes of 16 feet divided into 4 equal falls, which is absurd. But if we count their momentums to be as the squares of their velocities, the effects will be equal.

Again, it is evident that whatever impulse or force is required to give a body a velocity, the same force or resistance will be required to stop it; therefore, if the impulse be as the square of the velocity produced, the force or resistance will be as the squares of the velocity also. But the impulse is as the squares of the velocity produced, which is evident from this consideration, Suppose we place a light body at the gate B, of 4 feet head, and pressed with 4 feet of water; when the gate is drawn it will fly off with a velocity of 16 feet per second; and if we increase the head to 16 feet, it will fly off with 32 feet per second. Then, as the square of 16 equal to 256 is to the square of 32 equal to 1024, so is 4 to 16. Q. E. D.

ART. 47.

To compare this 7th law with the theory of undershot mills, established art. 42, where it is shewn that the power is to the effect as 3 to 1; then, by the 7th law, the quantity shewn by the scale, plate II, to be 32,4 multiplied by 1049,76 the square of the velocity, which is equal to 3401,2124, the effect of the 16 feet head; then, for the effect of a 4 feet head, with equal aperture quantity, by scale, 16,2 multiplied by 262,44, the velocity squared, is equal to 425,1528, the effect of a four feet head; here the ratio of the effects are as 8 to 1.

Then, by the theory, which shews that an undershot wheel will hoist 1-3 of the water that turns it, to the whole height from which it descended, the 1-3 of 32,4 the quantity, being equal to 10,8 multiplied by 16, perpendicular ascent, which is equal to 172,8, effect of a 16 feet head: and 1-3 of 16,2 quantity, which is equal to 5,4 multiplied by 4, perpendicular ascent, is equal to 21,6 effect of 4 feet head, by the theory: and here again the ratio of the effects are as 8 to 1; and,

as 3401,2124, the effect of 16 feet head, } by 7th law,
is to 425,1528, the effect of 4 feet head, }
so is 172,8 the effect of 6 feet head, } by the theory.
to 21,6 the effect of 4 feet head. }

The quantities being equal, their effects are as the height of their heads directly, as by 5th law, and as the squares of their velocities as by 7th law. Hence it appears, that the theory agrees with the established laws, which I take to be a confirmation that it is well founded.

8. Therefore their effects or powers with equal apertures, are as the cubes of their velocities.*

9. Their velocity under any head is equal to the velocity that a heavy body would acquire in falling from the same height.†

10. Their velocity is such under any head or height, as will pass over a distance equal to twice the height of the head, in a horizontal direction, in the time that a heavy body falls the distance of the height of the head.

11. Their action and re-action are equal.§

12. Their being non-elastic, communicate only half their real force by impulse, in striking obstacles; but by

* The effects of striking fluids with equal apertures are as the cubes of their velocities, for the following reasons, viz. 1st. If an equal quantity strike with double velocity, the effect is quadruple on that account by the 7th law; and a double velocity expends a double quantity by 3d law; therefore, the effect is amounted to the cube of the velocity.—The theory for undershot wheels agrees with this law also.

A SCALE

Founded on the 3d, 6th and 7th laws, shewing the effects of striking Fluids, with different Velocities.

Aperture.	Multiplied by the	Velocity.	Is equal the	Quantity expended.	Which multiplied by the	Square of the velocity.	Is equal the	Effect.	Which is as the	Cubes of the velocity.
1	×	1	=	1	×	1	=	1	as	1
1	×	2	=	2	×	4	=	8	as	8
1	×	3	=	3	×	9	=	27	as	27
1	×	4	=	4	×	16	=	64	as	64

† The falling body is acted on by the whole force of its own gravity, in the whole of its descent through any space; and the whole sum of this action that is acquired as it arrives at the lowest point of its fall, is equal to the pressure of the whole head or perpendicular height above the issue; therefore their velocities are equal.

‡ That is, they re-act back against the penstock with the same force that it issues against the obstacle it strikes; this is the principle by which Barker's mills, and all those that are improvements thereon, move.

their gravity produce effects, equal to elastic or solid bodies.*

Application of the Laws of Motion to Undershot Wheels.

To give a short and comprehensive detail of the ideas I have collected from the different authors, and from the result of my own reasoning on the laws of motion, and of spouting fluids, as they apply to move undershot mills, I constructed fig. 44, plate V.

Let us suppose two large wheels, one of 12 feet, and the other of 24 feet radius, then the circumference of the largest, will be double that of the smallest: and let A 16, and C 16, be two penstocks of water, of 16 feet head, each.

1. Then, if we open a gate of 1 square foot at 4, to issue from the penstock A 16, and impinge on the small wheel at I, the water being pressed by 4 feet head, will move 16 feet per second, (we omit fractions.) The instant pressure or force on that gate, being four cubic feet of water, it will require a resistance of 4 cubic feet of water, from the head C 16 to stop it, and hold it in equilibrio, (but we suppose the water cannot escape unless the wheel moves, so that no force be lost by non-elasticity.) Here equal quantities of matter, with equal velocities, have their momentums equal.

2. Again, suppose we open a gate of 1 square foot at A 16 under 16 feet head, it will strike the large wheel at k, with velocity 32, its instant force or pressure being 16 cubic feet of water, it will require 16 cubic feet resistance, from the head C 16, to stop or balance it. In this case the pressure or instant force is quadruple, and so is the resistance, but the velocity only double, to the first case. In these two cases, the forces and resistances

* When non-elastic bodies strike an obstacle, one half of their force is spent in a lateral direction, in changing their figure, or in splashing about. See art. 8.

For want of due consideration or knowledge of this principle, many have been the errors committed by applying water to act by impulse, when it would have produced a double effect by its gravity.

being equal quantities, with equal velocities, their momentums are equal.

3. Again, suppose the head C 16 to be raised to E, 16 feet above 4, and a gate drawn $\frac{1}{4}$ of a square foot, then the instant pressure on the float I of the small wheel, will be 4 cubic feet, pressing on $\frac{1}{4}$ of a square foot, and will exactly balance 4 cubic feet, pressing on 1 square foot, from the head A 16; and the wheel will be in equilibrio, (supposing the water cannot escape until the wheel moves as before), although the one has power of velocity 32, and the other only 16 feet per second. Their loads at equilibrio are equal, consequently their loads at a maximum velocity and charge, will be equal, but their velocities different.

Then, to try their effects, suppose, first, the wheel to move by the 4 feet head, its maximum velocity to be half the velocity of the water, which is 16, and its maximum load to half its greatest load, which is 4, by Waring's theory; then the velocity 16 | 2×by the load 4 | 2=16, the effect of the 4 feet head, with 16 cubic feet expended; because the velocity of the water is 16, and the gate 1 foot.

Again, suppose it to move by the 16 feet head and gate of $\frac{1}{4}$ of a foot; then the velocity 32 | 2×by the load 4 | 2=32, the effect, with but 8 cubic feet expended, because the velocity of the water is 32, and the gate but $\frac{1}{4}$ of a foot.

In this case the instant forces are equal, each being 4; but the one moving a body only $\frac{1}{4}$ as heavy as the other, moves with velocity 32, and produces effect 32, while the other, moving with velocity 16, produces effect 16. A double velocity, with equal instant pressure, produces a double effect, which seems to be according to the Newtonian theory. And in this sense the momentums of bodies in motion are as their quantities, multiplied into their simple velocities, and this I call the instant momentums.

But when we consider, that in the above case it was the quantity of matter put in motion, or water expended, that produced the effect, we find that the quantity 16, with velocity 16, produced effect 16; while qu. 8, with

velocity 32, produced effect 32. Here the effects are as their quantities, multiplied into the squares of their velocities; and this I call the effective momentums.

Again, if the quantity expended under each head, had been equal, their effects would have been 16 and 64, which is as the squares of their velocities, 16 and 32.

4. Again, suppose both wheels to be on one shaft, and let a gate of 1-8 of a square foot be drawn at 16 C, to strike the wheel at k, the head being 16 feet, the instant pressure on the gate will be 2 cubic feet of water, which is half of the 4 feet head with 1 foot gate, from A 4 striking at I; but the 16 feet head, with instant pressure 2, acting on the great wheel, will balance 4 feet on the small one, because the lever is of double length, and the wheels will be in equilibrio. Then, by Waring's theory, the greatest load of the 16 feet head being 2, its load at a maximum will be 1, and the velocity of the water being 32, the maximum velocity of the wheel will be 16. Now the velocity $16\times1=16$, the effect of the 16 feet head, and gate of 1-8 of a foot. The greatest load of the 4 feet head being 4, its maximum load 2, the velocity of the water 16, and the velocity of the wheel 8, now $8\times2=16$, the effect. Here the effects are equal: and here again the effects are as the instant pressures, multiplied into their simple velocities: and the resistances that would instantly stop them, must be equal thereto, in the same ratio.

But when we consider, that in this case the 4 feet head expended 16 cubic feet of water, with velocity 16, and produced effect 16; while the 16 feet head expended only 4 cubic feet of water, with velocity 32, and produced effect 16, we find, that the effects are as their quantities, multiplied into the squares of their velocities.

And when we consider, that the gate of 1-8 of a square foot, with velocity 32, produced effects equal to the gate of 1 square foot, with velocity 16, it is evident, that if we make the gates equal, the effects will be as 8 to 1; that is, the effects of spouting fluids, with equal apertures, are as the cubes of their velocities; because, their instant forces are as the squares of their velocities by 6th law, although the instant force of solids are as their velocities,

simply, and their effects as the squares of their velocities, a double velocity does not double the quantity of a solid body to strike in the same time.

ART. 48.

THE HYDROSTATIC PARADOX.

The pressure of fluids is as their perpendicular heights, without any regard to their quantity: and their pressure upwards is equal to their pressure downwards. In short, their pressure is every way equal, at any equal distance from their surface.*

* To explain which, let A B C D, plate III, fig. 22. be a vessel of water of a cubical form, with a small tube as H, fixed therein; let a hole of the same size of the tube be made at o, and covered with a piece of pliant leather, nailed thereon, so as to hold the water. Then fill the vessel with water by the tube H, and it will press upwards against the leather, and raise it in a convex form, requiring just as much weight to press it down, as will be equal to the weight of water in the tube H. Or if we set a glass tube over the hole at o, and pour water therein, we will find that the water in the tube o, must be of the same height of that in the tube H, before the leather will subside, even if the tube O be much larger than H; which shews, that the pressure upwards is equal to the pressure downwards; because the water pressed up against the leather with the whole weight of the water in the tube H. Again, if we fill the vessel by the tube I, it will rise to the same height in H that it is in I; the pressure being the same in every part of the vessel as if it had been filled by H; and the pressure on the bottom of the vessel will be the same, whether the tube H be of the whole size of the vessel, or only one quarter of an inch diameter. For suppose H to be 1-4 of an inch diameter, and the whole top of the vessel of leather as at o, and we pour water down H, it will press the leather up with such force, that it will require a column of water of the whole size of the vessel, and height of H, to cause the leather to subside. Q. E. D.

ART. 49.

And again, suppose we make two holes in the vessel, one close to the bottom, and the other in the bottom, both of one size, the water will issue with equal velocity out of each; which may be proved by holding equal vessels under each, which will be filled in equal time; which shews, that the pressure on the sides and bottom are equal under equal distances from the surface. And this velocity will be the same whether the tube be filled by pipe I, or H, or by a tube the whole size of the vessel, provided the perpendicular height be equal in all cases.

From what has been said, it appears, that it makes no difference in the power of water on mill-wheels, whether it be brought on in an open fore-bay and perpendicular penstock, or down an inclining one, as I C; or under ground in a close trunk, in any form that may best suit the situation and

In a vessel of cubic form, whose sides and bottom are equal, the pressure on each side is just half the pressure on the bottom; therefore the pressure on the bottom and sides, is equal to three times the pressure on the bottom.*

And in this sense fluids may be said to act, with three times the force of solids. Solids act by gravity only, but fluids by gravity and pressure jointly. Solids act with a force proportional to their quantity of matter; but fluids act with a pressure proportional to their altitude only.

ART. 50.

The weight of a cubic foot of water is found by experience, to be 1000 ounces avoirdupoise, or 62,5lb. On these priciples is founded the following

THEOREM.

The area of the base or bottom, or any part of a vessel, of whatever form, multiplied by the greatest perpendicular height of any part of the fluid, above the centre of the base or bottom, whatever be its position with the horizon, produces the pressure on the bottom of said vessel.

PROBLEM I.

Given, the length of the sides of the cubic vessel (fig. 22, pl. III.) 6 feet required the pressure on the bottom when full of water.

Then $6 \times 6=36$ feet the area, multiplied by 6, the altitude,$=216$, the quantity or cubic feet of water, pressing on the bottom; which multiplied by $62,5=13500$lb. the whole pressure on the bottom.

circumstances, provided that the trunk be large enough to supply the water fast enough to keep the head from sinking.

This principle of the Hydrostatic Paradox has sometimes taken place in undershot mills, by pressing up against the bottom of the buckets, thereby destroying or counteracting great part of the force of impulse. See art. 59.

* For demonstration, see Philosophia Britannia.

PROBLEM II.

Given, the height of a penstock of water, 31,5 feet, and its dimensions at bottom 3 by 3 feet, inside, required the pressure on 3 feet high of one of its sides,

Then, $3\times3=9$ the area, multiplied by 30 feet, the perpendicular height or head above its centre=270 cubic feet of water pressing, which $\times62,5=16875$lb. the pressure on one yard square, which shews what great strength is required, to hold the water under such great heads.

ART. 51.

RULE FOR FINDING THE VELOCITY OF SPOUTING WATER.

By experiments it has been found, that water will spout from under a 4 feet head, with a velocity equal to 16,2 feet per second, and from under 16 feet head, with a velocity equal to 32,4 feet per second.

On these experiments, and the 2nd law of spouting fluids, is founded the following theorem, or general rule for finding the velocity of water under any given head.

THEOREM II.

As the square root of a four feet head (=2) is to 16,2 feet, the velocity of the water, spouting under it, so is the square root of any other head, to the velocity of the water spouting under it.

PROBLEM I.

Given, the head of water 16 feet, required the velocity of water spouting under it.

Then, as the square root of 4 (=2) is to 16,2, so is the square root of 16, (=4) to 32,4, the velocity of the water under the 16 feet head.

PROBLEM II.

Given, a head of water of 11 feet, required the velocity of water spouting under it.

Then, as 2:16,2::3,316:26,73 feet per second, the velocity required.

ART. 52.

From the laws of spouting fluids, theorems I. and II. the theory for finding the maximum charge and velocity of undershot wheels. (art. 42) and the principle of non-elasticity, is deduced the following theorem for finding the effect of any gate, drawn under any given head, upon an undershot water-wheel.

THEOREM III.

Find by theorem I. (art. 50) the instantaneous pressure of the water, which is the load at equilibrio, and 2-3 thereof is the maximum load, which, multiplied by ,577 of the velocity of the water, under the given head, (found by theorem II.) produces the effect.

PROBLEM.

Given, the head 16 feet, gate 4 feet wide, ,25 of a foot drawn, required the effect of an undershot wheel, per second. The measure of the effect to be the quantity, multiplied into its distance moved, (velocity) or into its perpendicular ascent.

Then by theorem I. (art. 50) $4 \times ,25 = 1$ square foot the area of the gate $\times\ 16 = 16$ the cubic feet pressing; but, for the sake of round numbers, we call each cubic foot 1, and although 32,4 cubic feet strike the wheel per second, yet, on account of non-elasticity, only 16 cubic feet is the load at equilibrio, and 2-3 of 16 is 10,666, the maximum load.

Then, by theorem II. the velocity is 32,4, ,577 of which is$=$18,71, the maximum velocity of the wheel $\times$ 10,66, the load$=$199,4, the effect.

This agrees with Smeaton's observations, where he says, (art. 67) "It is somewhat remarkable, that though the velocity of the wheel, in relation to the velocity of the water, turn out to be more than 1-3, yet the impulse

of the water, in case of the maximum, is more than double of what is assigned by theory; that is, instead of 4-9 of the column, it is nearly equal to the whole column." Hence I conclude, that non-elasticity does not operate so much against this application, as to reduce the load to be less than 2-3. And when we consider, that 32,4 cubic feet of water, or a column 32,4 feet long, strike the wheel while it moves only 18,71 feet, the velocity of the wheel being to the velocity of the water as 577 to 1000, may not this be the reason why the load is just 2-3 of the head, which brings the effect to be just ,38 (a little more than 1-3 of the power.) This I admit because it agrees with experiment, although it be difficult to assign the true reason thereof. See annotation, art. 42.

Therefore ,577 the velocity of the water=18,71, multiplied by 2-3 of 16, the whole column, or instantaneous pressure, pressing on the wheel—art. 50—which is 10,66, produces 199,4 the effect. This appears to be the true effect, and if so, the true theorem will be as follows, viz.

THEOREM.

Find, by theorem I. art. 50, the instantaneous pressure of the water, and take 2-3 for the maximum load; multiply by ,577 of the velocity of the water—which is the velocity of the wheel—and the product will be the effect.

Then 16 cubic feet, the column, multiplied by 2-3= 10,66, the load which multiplied by 18,71 the velocity of the wheel, produces 199,4, for the effect; and if we try different heads and different apertures, we find the effects to bear the ratio to each other, that is agreeable to the laws of spouting fluids.

ART. 53.

WATER APPLIED ON WHEELS TO ACT BY GRAVITY.

But when fluids are applied to act on wheels to produce effects by their gravity, they act on very different

principles, producing double effects, to what they do by percussion, and then their powers are directly as their quantity or weight, multiplied into their perpendicular descent.

DEMONSTRATION.

Let fig. 19, plate III. be a lever, turning on its centre or fulcrum A. Let the long arm A B represent the perpendicular descent, 16 feet, the short arm A D a descent of 4 feet, and suppose water to issue from the trunk F, at the rate of 50lb. in a second, falling into the buckets fastened to the lever at B. Now, from the principles of the lever—art. 16—it is evident, that 50lb. in a second at B, will balance 200lb. in a second, at D, issuing from the trunk G, on the short arm; because $50\times16=4\times200=800$, each. Perhaps it may appear plainer if we suppose the perpendicular line or diameter F C, to represent the descent of 16 feet, and the diameter G I a descent of 4 feet. By the laws of the lever—art. 16—it is shewn, that, to multiply 50 into its perpendicular descent 16 feet or distance moved, is=200, multiplied into its perpendicular descent 4 feet, or distance moved; that is, $50\times16=200\times4=800$; that is, their power is as their quantity, multiplied into their perpendicular descent; or in other words, a fall of 4 feet will require 4 times as much water, as a fall of 16 feet, to produce equal power and effects. Q. E. D.

Upon these principles is founded the following simple theorem, for measuring the power of an undershot mill, or of a quantity of water, acting upon any mill-wheel by its gravity.

THEOREM IV.

Cause the water to pass along a regular canal, and multiply its depth in feet and parts, by its width in feet and parts, for the area of its section, which product multiply by its velocity per second in feet and parts, and the product is the cubic feet used per second, which multiplied by 62,5lb. the weight of 1 cubic foot, pro-

duces the weight of water per second, that falls on the wheel, which multiplied by its whole perpendicular descent, gives a true measure of its power.

PROBLEM I.

Given, a mill-seat with 16 feet fall, width of the canal 5,333 feet, depth 3 feet, velocity of the water passing along it 2,03 feet per second, required the power per second.

Then, 5,333×3=15,999 feet, the area of the section of the stream, multiplied by 20,3 feet, the velocity, is equal 32,4 cubic feet, the quantity per second, multiplied by 62,5 is equal 2025lb. the weight of the water per second, multiplied by 16, the perpendicular descent, is equal 32400, for the power of the seat per second.

PROBLEM II.

Given, the perpendicular descent 18,3, width of the gate 2,66 feet, height ,145 of a foot, velocity of the water per second, issuing on the wheel 15,76 feet, required the power.

Then, 266×,145=,3857 the area of the gate, ×15,76 the velocity=6,178 cubic feet, expended per second ×62,5=375,8lb. per second ×18,3 feet perpendicular descent=6877 for the measure of the power per second, which ground 3,75lb. per minute, equal 3,75 bushels in an hour, with a five feet pair of burr stones.

ART. 54.

INVESTIGATION OF THE PRINCIPLES OF OVERSHOT MILLS.

Some have asserted, and many believed, that water is applied to great disadvantage on the principle of an overshot mill; because, say they, there are never more than two buckets, at once, that can be said to act fairly on the end of the lever, as the arms of the wheel are called in these arguments. But we must consider well the laws of bodies descending inclined planes, and curved surfaces. See art. 10, 11. This matter will be cleared up,

if we consider the circumference of the wheel to be the curved surface: for the fact is, that the water acts to the best advantage, and produces effects equal to what it would, in case the whole of it acted upon the very end of the lever, in the whole of its perpendicular descent.*

DEMONSTRATION.

Let A B C, Plate III. fig. 20, represent a water-wheel, and F H a trunk, bringing water to it from a 16 feet head. Now suppose F G and 16 H to be two penstocks under equal heads, down which the water descends, to act on the wheel at C, on the principle of an undershot, on opposite sides of the float C, with equal apertures. Now it is evident from the principles of hydrostatics, shewn by the paradox, (art. 48, and the first law of spouting fluids art. 45,) that the impulse and pressure will be equal from each penstock respectively. Although the one be an inclined plane, and the other a perpendicular, their forces are equal, because their perpendicular heights are; (art. 48) therefore the wheel will remain at rest, because each side of the float is pressed on by a column of water of equal size and height, as represented by the lines on each side of the float. Then suppose we shut the penstock F G, and let the water down the circular one r x, which is close to the point of the buckets; this makes it obvious, from the same principles, that the wheel will be held in equilibrio, if the columns of each side be equal. For, although the column in the circular penstock, is longer than the perpendicular one, yet, because part of its weight presses on the lower side of the penstock, its pressure on the float is only equal to the perpendicular.

Then, again, suppose the column of water in the circular penstock, to be instantly thrown into the buckets, it is evident, that the wheel will still be held in equilibrio, and each bucket will then bear a proportional part of the column, that the bucket C bore before; and that part of the weight of the circular column, which rested on the under side of the circular penstock, is now on the

* This error has been the cause of many expensive errors in the application of water.

gudgeons of the wheel. This shews that the effect of a stream, applied on an overshot wheel, is equal to the effect of the same stream, applied on the end of the lever, in its whole perpendicular descent, as in fig. 21, where the water is shot into the buckets fastened to a strap or chain, revolving over two wheels; and here the whole force of the gravity of the column acts on the very end of the lever, in the whole of the descent. Yet, because the length of the column in action, in this case, is only 16 feet; whereas on a 16 feet wheel the length of the column in action is 25,15, therefore the powers are equal.

Again, if we divide the half circle into 3 inches Ab, be, eC, the centre of gravity of the upper and lower arches, will fall near the point a, 3,9 feet from the centre of motion, and the centre of gravity of the middle arch, near the point o, 7,6 feet from the centre of motion. Now each of these arches is 8,38 feet, and $8{,}38 \times 2 \times 3{,}9 = 65{,}36$, and $8{,}38 \times 7{,}6$ feet$=63{,}07$, which two products added$=$ 128,43, for the momentum of the circular column, by the laws of the lever, and for the perpendicular column 16×8 the radius of the wheel$=128$, for the momentum; by which it appears, that if we could determine the exact points on which the arches act, the momentums would be equal, all which shews, that the power of water on overshot wheels, is equal to the whole power it can any way produce, through the whole of its perpendicular descent, except what may be lost to obtain velocity, (art. 41) overcome friction, or by part of the water spilling, before it gets to the bottom of the wheel. Q. E. D.

I may add, that I have made the following experiment, viz. I fixed a truly circular wheel on nice pivots, to evade friction, and took a cylindric rod of thick wire, cutting one piece exactly the length of half the circumference of the wheel, and fastening it to one side, close to the rim of the wheel its whole length, as at G x r a. I then took another piece of the same wire, of a length equal to the diameter of the wheel, and hung it on the opposite side, on the end of the lever or arm, as at B, and the wheel was in equilibrio. Q. E. D.

ART. 55.

OF THE FRICTION OF THE APERTURES OF SPOUTING FLUIDS.

The doctrine of this species of friction appears to be as follows;

1. The ratio of the friction of round apertures, are as their diameters, nearly, while their quantities expended, are as the squares of their diameters.

2. The friction of an aperture, of any regular or irregular figure, is as the length of the sum of the circumscribing lines, nearly; the quantities being as the areas of the aperture.* Therefore,

3. The less the head or pressure, and the larger the aperture, the less the ratio of the friction; therefore,

4. This friction need not be much regarded, in the large openings or apertures of undershot mills, where the gates are from 2 to 15 inches on their shortest sides; but it very sensibly affects the small apertures of high overshot or undershot mills, with great heads, where their shortest sides are from five-tenths of an inch to two inches.†

ART. 56.

OF THE PRESSURE OF THE AIR ON FLUIDS.

The second cause of the motion or rise of fluids, is the pressure of the air on the surface of them, in the

* This will appear, if we consider and suppose, that the friction does sensibly retard the velocity of the fluid to a certain distance. Say half an inch from the side or edge of the aperture, towards its centre; and we may reasonably conclude, that this distance will be nearly the same in a 2 and 12 inch aperture; so that in the 2 inch aperture, a ring on the outside, half an inch wide, is sensibly retarded, which is about 3-4 of the whole; while, in the 12 inch aperture, there is a ring on the outside half an inch wide, retarded about 1 6 of its whole area.

† This seems to be proved by Smeaton, in his experiments; (see table, art. 67) where, when the head was 33 inches, the sluice small, drawn only to the 1st hole, the velocity was only such as is assigned by theory, to a head of 15,85 inches, which he calls virtual head. But when the sluice was larger, drawn to the 6th hole, and head 6 inches, the virtual head was 5,33 inches. But seeing there is no theorem yet discovered by which we can truly determine the quantity or effect of their friction, according to the size of the aperture, and height of the head; therefore, we cannot, by the established laws of hydrostatics, determine exactly the velocity or quantity expended through any small aperture; which renders the theory but little better than conjecture in these cases.

fountain or reservoir; and this pressure is equal to a head of water of 33 1-3 feet perpendicular height, under which pressure or height of head, the velocity of spouting water is 46,73 feet per second.

Therefore, if we could by any means take off the pressure of the atmosphere, from any one part of the surface of a fluid, that part would spout up with a velocity of 46,73 feet per second, and rise to the height of 33 1-3 feet nearly.*

On this principle act all syphons or cranes, and all pumps for raising water by suction, as it is called.—Let fig. 23, pl. III. represent a cask of water, with a syphon therein, to extend 33 1-3 feet above the surface of the water in the cask. Now if the bung be made perfectly air-tight, round the syphon, so that no air can get into the cask, and the cask be full, then, if all the air be drawn out of the syphon, at the bended part A, the fluid will not rise in the syphon, because the air cannot get to it to press it up; but take out the plug P, and let the air into the cask, to press on the surface of the water, and it will spout up the short leg of the syphon B A, with the same force and velocity, as if it had been pressed with a head of water 33 1-3 feet high, and will run into the long leg and will fill it. Then if we turn the cock c, and let the water run out, its weight in the long leg will overbalance the weight in the short one, drawing the water out of the cask until the water sink so low, that the leg B A will be 33 1-3 feet high, above the surface of the water in the cask; then it will stop, because the weight of water in the leg, in which it rises, will be equal to the weight of a column of the air of equal size, and of the whole height of the atmosphere. The water will not run out of the leg A c, but will stand full 33 1-3

* This seems to be the principle of whirlwinds at sea, called water spouts; the wind meeting from different points, forms a quick circular motion; and by the centrifugal force forms a partial vacuum in the centre, which gives liberty to the water to rise a little, which is by the rapidity of the motion of the air, rent into very small particles: which so increases the surface, that the air takes sufficient hold of it to carry it up. And as the wind meeting has no way to vent itself but in a perpendicular direction, therefore, a brisk current is formed upwards, carrying the water with it, at sea; but on the land, it raises leaves of trees and other light bodies. See Franklin's Letters.

feet above its mouth, because the air will press up the mouth c, with a force that will balance 30 1-3 feet of water in the leg c A. This will be the case, let the upper part of the leg be any size whatever—and there will be a small vacuum in the top of the long leg.

ART. 57.

OF PUMPS.

Let fig. 24, pl. III. represent a pump of the common kind used for drawing water out of wells. The moveable valve or bucket A, is cased with leather, which springs outwards, and fits the tube so nicely, that neither air nor water can pass freely by it. When the lever L is worked, the valve A opens as it descends, letting the air or water pass through it. As it ascends again the valve shuts; the water which is above the bucket A is raised, and there would be a vacuum between the valves, but the weight of the air presses on the surface of the water in the well, at W, forcing it up through the valve B, to fill the space between the buckets; and as the valve A descends, B shuts, and prevents the water from descending again: But if the upper valve A be set more than 33 1-3 feet above the surface of the water in the well, the pump cannot be made to draw, because the pressure of the atmosphere will not cause the water to rise more than 33 1-3 feet.

N

A TABLE FOR PUMP-MAKERS.

Height of the pump in feet above the surface of the well.	Diameter of the bore.		Water discharged in a minute in wine measure.	
	inches.	100 parts of an inch.	Galls.	Pints.
10	6	93	81	6
15	5	66	54	4
20	4	90	40	7
25	4	38	32	6
30	4	00	27	2
35	3	70	23	3
40	3	46	20	3
45	3	27	18	1
50	3	10	16	3
55	2	95	14	7
60	2	84	13	5
65	2	72	12	4
70	2	62	11	5
75	2	53	10	7
80	2	45	10	2
85	2	38	9	5
90	2	31	9	1
95	2	25	8	5
100	2	19	8	1

"All pumps should be so constructed as to work with equal ease, in raising the water to any given height above the surface of the well: and this may be done by observing a due proportion between the diameter of that part of the pump-bore in which the piston or bucket works, and the height to which the water must be raised.

"For this purpose I have calculated the above table, in which the handle of the pump is supposed to be a lever, increasing the power five times: that is, the distance or length of that part of the handle that lies between the pin on which it moves, and the top of the pump-rod to which it is fixed, to be only one fifth part of the length of the handle, from the said pin to the part where the man (who works the pump) applies his force or power.

"In the first column of the table, find the height at which the pump must discharge the water above the surface of the well; then in the second column, you have the diameter of that part of the bore in which the piston or bucket works, in inches and hundredth parts of an inch; in the third column is the quantity of water, (in mine weasure) that a man of common strength can raise in a minute.—And by constructing according to this method, pumps of all heights may be wrought by a man of ordinary strength so as to be able to hold out for an hour."

JAMES FERGUSON.

ART. 58.

OF CONVEYING WATER UNDER VALLEYS AND OVER HILLS.

Water, by its pressure, and the pressure of the atmosphere, may be conveyed under valleys and over hills, to supply a family, a mill, or a town. See fig. 20, pl. III. F H is a canal for conveying water to a mill-wheel. Now let us suppose F G 16 H to be a tight tube or trunk—the water being let in at F, it will descend from F to G, and its pressure at F will cause it to rise to H, passing along if permitted, and may be conveyed over a hill by a tube, acting on the principle of the syphon. (art. 56.) But where some have had occasion thus to convey water under any obstacle for the convenience of a mill, which often occurs in practice, they have gone into the following expensive error: They make the tube at G 16 smaller than if it had been on a level, because, say they, a greater quantity will pass though a tube, pressed by the head G F, than on a level. But they should consider that the head G F is balanced by the head H 16, and the velocity through the tube G 16 will only be such that a head equal to the difference between the perpendicular height of G F and H 16 would give it; (see art. 41, fig. 19,) therefore it should be as large at G 16 as if on a level.

ART. 59.

OF THE DIFFERENCE OF THE FORCE OF INDEFINITE AND DEFINITE QUANTITIES OF WATER STRIKING A WHEEL.

DEFINITIONS.

1. By an indefinite quantity of water we here mean a river or large quantity, much larger than the float of the wheel, so that, when it strikes the float, it has liberty to move or escape from it in every lateral direction.

2. By a definite quantity of water we mean a quantity passing through a given aperture along a shute to strike a wheel; but as it strikes the float, it has liberty to escape in every lateral direction.

3. By a perfectly definite quantity, we mean a quantity passing along a close tube so confined, that when it strikes the float, it has not liberty to escape in any lateral direction.

First, When a float of a wheel is struck by an indefinite quantity, the float is struck by a column of water, the section of which is equal to the area of the float; and as this column is confined on every side by the surrounding water, which has equal motion, it cannot escape freely sideways; therefore more of its force is communicated to the float than would be, in case it had free liberty to escape sideways in every direction.

Secondly, The float being struck by a definite quantity, with liberty to escape freely in every side direction, it acts as the most perfect non-elastic body; therefore (by art. 8) it communicates only a part of its force, the other part being spent in the lateral direction. Hence it appears, that in the application of water to act by impulse, we should draw the gate as near as possible to the float-board, and confine it as much as possible from escaping sideways as it strikes the float; but, taking care at the same time, that we do not bring the principle of the Hydrostatic Paradox into action. (art. 48.)

What proportion of the force of the water is spent in a lateral direction is not yet determined, but see Art. 8.

4. A perfectly definite quantity striking a plane, communicates its whole force; because no part can escape sideways, and is equal in power to an elastic body, or the weight of the water on an overshot wheel, in its whole perpendicular descent. But this application of water to wheels has been hitherto impracticable; for whenever we attempt to confine the water totally from escaping sideways, we bring the paradoxical principle into action, which defeats the scheme.*

* But this difficulty is now overcome by the valve wheel. See annotation, art. 73.

To make this plain, let fig. 25, pl. III. be a water-wheel; and first, let us suppose the water to be brought to it by the penstock 4.16, to act by impulse on the float board, having free liberty to escape every way as it strikes; then by art. 8, it will communicate but half its force. But if it be confined both at sides and bottom and can escape only upwards, to which the gravity will make some opposition, it will communicate perhaps more than half its force, and will not re-act back against the float c. But if we put soaling to the wheel to prevent the water from escaping upwards, then the space between the floats will be filled, as soon as the wheel begins to be retarded, and the paradoxical principle, art. 48, is brought fully into action viz. the pressure of water is every way equal, and presses backwards against the bottom of the float c, with a force equal to its pressure on the top of the float b, and the wheel will immediately stop and be held in equilibrio, and will not start again although all resistance be removed. This we may call the paradoxical mill. There are many mills, where this principle is, in part, brought into action, which very much lessens their power.

ART. 60.

OF THE MOTION OF BREAST AND PITCH-BACK WHEELS.

Many have been of opinion, that when water is put to act on the wheel as at a (called a low breast) with 12 feet head, that then the 4 feet fall below the point of impact a, is totally lost, because, say they, the impulse of the 12 feet head, will require the wheel to move with such velocity to suit the motion of the water as to move before the action of gravity, therefore the water cannot act after the stroke. But if they will consider well the principles of gravity acting on falling bodies (art. 9), they will find, that, if the velocity of a falling body be

ever so great, the action of gravity is still the same to cause it to move faster, so that, although an overshot wheel may move before the power of the gravity, of the water thereon, yet no impulse downwards can give a wheel such velocity, as that the gravity of the water acting thereon can be lessened thereby.*

Hence it appears, that when a greater head is used, than what is necessary to shoot the water fairly into the wheel, the impulse should be directed downward a little as at D, (which is called pitch-back,) and have a circular sheeting to prevent the water from leaving the wheel, because if it be shot horizontally on the top of a wheel, the impulse in that case will not give the water any greater velocity downwards; then, in this case, the fall would be lost, if the head was very great, and the wheel moved to suit the velocity of the impulse, the water would be thrown out of the buckets by the centrifugal force; and if we attempt to retard the wheel, so as to retain the water, the mill will be so ticklish and unsteady, that it will be almost impossible to attend it.

Hence may appear the reason why breast-wheels generally run quicker than overshots, although the fall after the water strikes be not so great.

1. There is generally more head allowed to breast-mills than overshots, and the wheel will incline to move with nearly 2-3 the velocity of the water, spouting from under the head, (art. 41.)

2. If the water was permitted to fall freely after it issues from the gate, it would be accelerated by the fall, so that its velocity at the lowest point would be equal to its velocity, had it spouted from under a head equal to its whole perpendicular descent. This accelerated velocity of the water, tends to accelerate the wheel; hence, to find the velocity of a breast-wheel, where the water is struck on in a tangent direction as in fig. 31, 32, I deduce the following

* If gravity could be either decreased by velocity downwards, or increased by velocity upwards, then a vertical wheel without friction, either of gudgeons or air, would require a great force to continue its motion; because, its velocity would decrease the gravity of its descending side, and increase it on its ascending side, which would immediately stop it: whereas it is known, that it requires no power to continue its motion, but what is necessary to overcome the friction of the gudgeons, &c.

THEOREM.

1. Find the difference of the velocity of the water under the head allowed to the wheel, above the point of impact, and the velocity of a falling body, having fell the whole perpendicular descent of the water. Call this difference the acceleration by the fall: Then say, As the velocity of a falling body acquired in falling through the diameter of any overshot wheel, is to the proper velocity of that wheel by the scale, (art. 43) so is the acceleration by the fall, to the acceleration of the wheel by the fall, after the water strikes the wheel.

2. Find the velocity of the water issuing on the wheel; take ,577 of said velocity, to which add the accelerated velocity, and that sum will be the velocity of the breast-wheel.

This rule will hold nearly true, when the head is considerably greater than is assigned by the scale (art. 43); but as the head approaches that assigned by the scale, this rule will give the motion too quick.

EXAMPLE.

Given, a high breast-wheel, fig. 25, where the water is shot on at d, the point of impact—6 feet head, and 10 feet fall—required the motion of the circumference of the wheel, working to the best advantage, or maximum effect.

Then, the velocity of the water, issuing on the wheel, 6 feet head,	19,34 feet.
The velocity of a falling body, having 16 feet fall, the whole descent,	32,4 do.
Difference, - -	13,06 do.

Then, as the velocity under a 16 feet fall (32,4 feet) is to the velocity of an overshot wheel=8,76 feet, so is 13,06 feet, to the 16 feet diameter velocity accelerated, which is equal 3,5 feet, to which add, 577 of 19,34 feet (being 11,15 feet); this amounts to 14,65 feet per second, the velocity of the breast-wheel.

ART. 61.

RULE FOR CALCULATING THE POWER OF ANY MILL-SEAT.

The only loss of power sustained by using too much head, in the application of water to turn a mill-wheel, is from the head producing only half its power. Therefore, in calculating the power of 16 cubic feet per second, on the different applications of fig. 25, pl. III. we must add half the head to the whole fall, and count that sum the virtual perpendicular descent. Then by theorem IV. (art. 53) multiply the weight of the water per second by its perpendicular descent, and you have the true measures of its power.

But to reduce the rule to a greater simplicity, let us call each cubic foot 1, and the rule will be simply this—Multiply the cubic feet expended per second, by its virtual perpendicular descent in feet, and the product will be a true measure of the power per second. This measure must have a name, which I call Cuboch; that is, one cubic foot of water, multiplied by one foot descent, is one cuboch, or the unit of power.

EXAMPLES.

1. Given, 16 cubic feet of water per second, to be applied by percussion alone, under 16 feet head, required the power per second.

Then, half $16=8\times16=128$ cubochs, for the measure of the power per second.

2. Given, 16 cubic feet per second, to be applied to a half breast of 4 feet fall and 12 feet head, required the power.

Then, half $12=6+4=10\times16=160$ cubochs, for the power.

3. Given, 16 cubic feet per second, to be applied to a pitch-back or high breast—fall 10, head 6 feet, required the power.

Then, half $6=3+13=10\times16=208$ cubochs, for the power per second.

4. Given, 16 cubic feet of water per second, to be applied as an overshot—head 4, fall 12 feet, required the power.

Then, half $4=2+12=14\times16=224$ cubochs, for the power.

The powers of equal quantities of water 16 cubic feet per second, and equal total perpendicular descents by the different applications, stand thus:

The undershot,	16 feet head,* 0 fall, 128 cubochs of power.
The half breast,	12 feet head, 4 feet fall, 160 cubochs of power.
The high breast,	6 feet head, 10 feet fall, 208 cubochs of power.
The overshot,	4 feet head, 12 feet fall, 224 cubochs of power.
Ditto,	2,5 feet head, 31,5 feet fall, 263 cubochs of power.

The last being the head necessary to shoot the water fairly into the buckets, may be said to be the best application. See art. 43.

* Water by percussion spends its force on the wheel in the following time, which is in proportion to the distance of the float-board, and difference of the velocity of the water and wheel.

If the water runs with double the velocity of the wheel, it will spend all its force on the floats, while the water runs the distance of two float-boards, and while the wheel runs the distance of one; therefore the water need not be kept to act on the wheel from the point of impact further than the distance of about two float-boards.

But if the wheel runs with two-thirds of the velocity of the water, then, while the wheel runs the distance of two floats, and while the water would have ran the distance of three floats, it spends all its force; therefore the water need be kept to act on the wheel only the distance of three floats past the point of impact.

If it be continued in much longer it will fall back, and re-act against the following bucket and retard the wheel.

On these simple rules, and the rule laid down in art. 43, for proportioning the head and fall, I have calculated the following table or scale of the different quantities of water expended per second, with different perpendicular descents, to produce a certain power, in order to present at one view to the reader the ratio of increase or decrease of quantity, as the perpendicular descent increases or decreases.

A TABLE

Shewing the quantity of water required with different falls, to produce by its gravity, 112 cubochs of power, which will drive a five feet stone about 97 revolutions in a minute, grinding wheat about 5 bushels in an hour.

The virtual descent of the water being half the head added to all the fall after it strikes the wheel.	Cubic feet of water required per second, &c.	The virtual descent of the water being half the head added to all the fall after it strikes the wheel.	Cubic feet of water required per second.
1	112	16	7,
2	56	17	6,58
3	37,3	18	6,22
4	28	19	5,99
5	22,4	20	5,6
6	18,6	21	5,33
7	16,	22	5,1
8	14	23	4,87
9	12,4	24	4,66
10	11,2	25	4,48
11	10,2	26	4,3
12	9.33	27	4,15
13	8,6	28	4,
14	8,	29	3,86
15	7,46	30	3,73

ART. 62.

THEORY AND PRACTICE COMPARED.

I will here give a table of 18 mills in actual practice out of about 50 that I have taken an account of, in order

to compare theory with practice, and in order to ascertain the power required on each superficial foot of the acting parts of the stone: But I must premise the following

THEOREMS.

1. To find the circumference by the diameter, or the diameter by the circumference of a circle given; say,

As 7 is to 22, so is the diameter of the stone to the circumference, *i. e.* Multiply the diameter by 22, and divide the product by 7, for the circumference; or, multiply the circumference by 7, and divide the product by 22, for the diameter.

2. To find the area of a circle by the diameter given: As 1, squared, is to ,7854, so is the square of the diameter to the area; *i. e.* Multiply the square of the diameter by ,7854, and deduct 1 foot for the eye, and you have the area of the stone.

3. To find the quantity of surface passed by a millstone: The area, squared, multiplied by the revolutions of the stone, gives the number of superficial feet, passed in a given time.

OBSERVATIONS ON THE FOLLOWING TABLE OF EXPERIMENTS.

I have asserted in art. 44, that the head above the gate of a wheel, on which the water acts by its gravity, should be such, as to cause the water to issue on the wheel, with a velocity to that of the wheel as 3 to 2, to compare this with the following table of experiments.

1. Exp. Overshot. Velocity of the water 12,9 feet per second, velocity of the wheel 8,2 feet per second, which is a little less than 2-3 of the velocity of the water. This wheel received the water well. It is at Stanton, in Delaware state.

2. Overshot. Velocity of the water 11,17 feet per second, 2-3 of which is 7,44 feet, velocity of the wheel 8,5 feet per second. This received the water pretty well. It is at the above-mentioned place.

3. Overshot. Velocity of the water 12,16 feet per second, velocity of the wheel 10,2; throws out great

part of the water by the back of the buckets; strikes it and makes a thumping noise. It is allowed to run too fast; revolves faster than my theory directs. It is at Brandywine, in Delaware state.

4. Overshot. Velocity of the water 14,4 feet per second, velocity of the wheel 9,3 feet, a little less than 2-3 of the velocity of the water. It receives the water very well; has a little more head than assigned by theory, and runs a little faster; it is a very good mill, situate at Brandywine, in the state of Delaware.

6. Undershot. Velocity of the wheel, loaded, 16, and when empty 24 revolutions per minute, which confirms the theory of motion for undershot wheels. See art. 42.

7. Overshot. Velocity of the water 15,79 feet, velocity of the wheel 7,8 feet; less than 2-3 of the velocity of the water; motion slower and head more than assigned by theory. The miller said the wheel ran too slow, and would have her altered; and that she worked best when the head was considerably sunk. She is at Bush, Hartford county, Maryland.

8. Overshot. Velocity of the water 14,96 feet per second, velocity of the wheel 8,8 feet, less than 2-3, very near the velocity assigned by the theory; but the head is greater, and she runs best when the head is sunk a little; is counted the best mill; and is at the same place with the last mentioned.

9, 10, 11, 12. Undershot, open wheels. Velocity of the wheels when loaded 20 and 40, and when empty 28 and 56 revolutions per minute, which is faster than my theory for the motion of undershot mills. Ellicott's mills, near Baltimore, in Maryland, serve to confirm the theory.

14. Overshot. Velocity of the water 16,2 feet, velocity of the wheel 9,1 feet, less than 2-3 of the water, revolutions of the stone 114 per minute, the head near the same as by theory, the velocity of the wheel less, stone more. This shews her to be too high geared. She receives the water well, and is counted a very good mill, situate at Alexandria, in Virginia.

15. Undershot. Velocity of the water 24,3 per se-

cond, velocity of the wheel 16,67 feet, more than 2-3 the velocity of the water. Three of these mills are in one house, at Richmond, Virginia—they confirm the theory of undershots, being very good mills.

16. Undershot. Velocity of the water 25,63 feet per second, velocity of the wheel 19,05 feet, being more than 2-3. Three of these mills are in one house, at Petersburg, in Virginia—they are very good mills, and confirm the theory. See art. 43.

18. Overshot wheel. Velocity of the water 11,4 feet per second, velocity of the wheel 10,96 feet, nearly as fast as the water. The backs of the buckets strike the water, and drive a great part over: and as the motion of the stone is about right, and the motion of the wheel faster than assigned by the theory, it shews the mill to be too low geared, all which confirms the theory. See art. 43.

In the following table I have counted the diameter of the mean circle to be two-thirds of the diameter of the great circle of the stone, which is not strictly true. The mean circle to contain half the area of any other circle must be ,707 parts of the diameter of the said circle, or nearly ,7 or 2-3.

Hence the following theorem for finding the mean circle of any stone.

THEOREM.

Multiply the diameter of the stone by ,707, and it produces the diameter of the mean circle.

EXAMPLE.

Given, the diameter of the stone 5 feet, required a mean circle that shall contain half its area.

Then, $5 \times ,707 = 3,535$ feet the diameter of the mean circle.

ART. 63.

FURTHER OBSERVATIONS ON THE FOLLOWING TABLE.

1. The mean power used to turn the 5 feet stones in the experiments (No. 1. 7. 14. 17.) is 87,5 cubochs of the measure established art. 6, and the mean velocity is 104 revolutions of the stones in a minute, the velocity of the mean circle being 18,37 feet per second, and their mean quantity ground is 3,8lb. per minute, which is 3,8 bushels per hour, and the mean power used to each foot of the area of the stone is 4,69 of the measure aforesaid, done by 36582 superficial feet passing each other in a minute. Hence we may conclude, until better informed,

1. That 87,5 cubochs of power per second will turn a 5 feet stone 104 revolutions in a minute, and grind 3-8 bushels in an hour.

2. That 4,69 cubochs of power is required to every superficial foot of a mill-stone, when their mean circles move with a velocity of 18,37 feet per second. Or,

3. That for every 36582 feet of the face of stones that pass each other we may expect 3,8lb. will be ground, when the stones, grain, &c. are in the state and condition, as were the above stones in the experiments.

A TABLE OF EXPERIMENTS OF EIGHTEEN MILLS IN PRACTICE.

Quantity ground per minute in pounds, or per hour in bushels.	Superficial feet passed in a minute.	Velocity of the mean circle.	Power required to each foot of face.	Area of the stones.	Diameter of the stone in feet and inches.	Revolutions of the stones per minute.	Rounds in the trundles.	Cogs in the counter cog-wheel.	Rounds in the wallowers.	Number of cogs in the master-wheel.	Velocity of the circumference per second.	Number of revolutions per minute.	Diameter of the wheel.	Power per second, by simple theorem. Art. 61.	Cubic feet expended per second, abating for friction by conjecture.	Velocity of the water per second, by theory.	Area of the gate, abating for contraction occasioned by friction.	Head above the centre of the gate.	Virtual or effective descent of the water.	Number of Experiments.
		feet.		sup. ft.	ft. in.								feet.	chs.	cub. ft.	feet.	feet.	feet.	feet.	
3.5	34594	17.3	4.1	18.63	5	99.7	15	54	27	88	8.2	8.	18	76	3.8	12.9	.385	2.67	20.	1
2.5	21514	18.5	4.34	13.13	4 3	124.8	14	48	22	88	8.5	9.	18	67	3.5	11.17	.325	1.9	19.2	2
					4 2	122	14	44	24	72	10.2	13	15			12.16		2.2	16.2	3
					4 8	122	14	44	24							14.4				
					4 6	104	14	44	24	66	9.3	12	15					3.1	16.6	4
		16.97			4 6	108	14	44	23											
		18.6			4 3	126	13	48	22	72	9.8	105	17.75			13.8		3	19.25	5
											loaded	16								
											unloaded	24	16							6
3.75	36435	18.32	4.9	18.63	5	105	14	44	22	78	7.8	9.5	16.4	92	5.18	15.79	.345	3.83	17.8	7
	35741	17.97	5.9	18.63	5	103	14	44	22	72	8.8	10	16.4	110	6.16	14.96	.425	3.5	17.8	8
	108091	17.84		38.48	7	73	23			84	loaded	20	15			26.73			11	9
											unloaded	28								
	36435	18.32			5	105	16			42	loaded	40	7.5							10
											unloaded	56								
					4 10	105	16			84	loaded	20	15							11
											unloaded	28								
	36435	18.32		18.63	5	105	16			42	loaded	40	7.5							12
											unloaded	56								
	95264	16.92		36.63	6 10	71	19	44	25	96	7.8	8	18.6			16.2		4	20.6	13
	49678	16.89		25.76	5 6	88	16	44	24											
4.5	39558	19.89	4.67	18.63	5	114	16	54	25	96	9.1	9	19.3	86	3.57	16.2		4	21.5	14
		20.75			5 4	113	17			60	16.67	32	10			24.3			9.5	15
	74850	19.9		28.38	6	95	21			44	19.05	45.5	8			25.63			10	16
3.5	35741	17.97	5.15	18.63	5	103	14	44	23	66	9.2	16	11	96	7.6	14	.567	3	12.5	17
					4 4	124	15	48	26	72	10.96	14	14			11.4		2		18
					4 8	116	16	48	26											

In the 3d, 4th, 13th and 18th experiments, in the above table, there are two pair of stones to one water-wheel, the gears, &c. of which are shewn by the braces. If the reader will by a rule draw small lines between the experiments, the table will be easier read.

OBSERVATIONS CONTINUED FROM PAGE 110.

But as we cannot attain to a mathematical exactness in those cases, and as it is evident that all the stones in the said experiments have been working with too little power, because it is known that a pair of good burr stones of 5 feet diameter, will grind sufficiently well about 125 bushels in 24 hours; that is 5,2 bushels in an hour, which would require 6,4 power per second—we may say 6 cubochs per second, when 5 feet stones grind 5 bushels per hour, for the sake of simplicity. Hence we deduce the following simple theorem for determining the size of the stones to suit the power of any given seat, or the power required to any size of a stone.

THEOREM.

Find the power by the theorem in art. 61; then divide the power by 6, which is the power required, by 1 foot, and it will give you the area of the stone that the power will drive, to which add 1 foot for the eye, and divide by ,7854, and the quotient will be the square of the diameter: or, if the power be great, divide by the product of the area of any size stones you choose, multiplied by 6, and the quotient will be the number of stones the power will drive: or, if the size of the stone be given, multiply the area by 6 cubochs, and the product is the power required to drive it.

EXAMPLES.

1. Given, 9 cubic feet per second, 12 feet perpendicular, virtual, or effective descent, required the diameter of the stone suitable thereto.

Then, by art. 61, $9\times12=108$, the power, and $108 \mid 6=18$, the area, and $18\times1 \mid ,7854=24,2$ the root of which is 4,9 feet, the diameter of the stone required.

Observation 5th. The velocities of the mean circles of these stones in the table are some below and some above 18 feet per second, the mean of them all being nearly 18 feet; therefore I conclude that 18 feet per second is a good velocity in general, for the mean circle of any sized stone.

Of the different quantity of Surfaces that are passed by Mill-stones of different diameters with different velocities.

Supposing the quantity ground by mill-stones and power required to turn them to be as the passing surfaces of their faces, each superficial foot that passes over another foot requires a certain power to grind a certain quantity: Then to explain this let us premise,

1. The circumference and diameter of circles are directly proportional. That is, a double diameter gives a double circumference.

2. The areas of circles are as the squares of their diameters. That is, a double diameter gives 4 times the area.

3. The square of the diameter of a circle multiplied by ,7854 gives its area.

4. The square of the area of a mill stone multiplied by its number of revolutions, gives the surface passed. Consequently,

5. Stones of unequal diameters revolving in equal times. Their passing surfaces, quantity ground, and power required to drive them, will be as the squares of their areas, or as the biquadrate of their diameters. That is, a double diameter will pass 16 times the surface.*

6. If the velocity of their mean circles or circumferences be equal their passing surfaces, quantity ground, and power required to move them, will be as the cubes of their diameters.†

7. If the diameters and velocities, be unequal, their passing surfaces and quantity ground, &c. will be as the squares of their areas, multiplied by their revolutions.

8. If their diameters be equal the quantity of surfaces passed, &c. are as their velocities or revolutions simply.

* The diameter of a 4 feet stone squared, multiplied by ,7854 equal 12,56 its area; which squared is 157,75 feet, the surface passed at one revolution: and 8 multiplied by 8 equal 64, which multiplied by ,7854 equal 50,24 being the area of an 8 feet stone; which squared is 2524,04 the surface passed, which surfaces are as 1 to 16.

† Because the 8 feet stone will revolve only half as often as the 4 feet, therefore their quantity of surface passed, &c. can only be half as much more as it was in the last case; that is, as 8 to 1.

But we have been supposing theory and practice to agree strictly, which they will by no means do in this case. The quantity ground and power used by large stones more than by small ones will not be in the ratio assigned by the theory; because the meal having to pass a greater distance through the stone, is operated upon oftener, which operations must be lighter, else it will be overdone; by which means large stones may grind equal quantities with small ones, and with equal power, and do it with less pressure; therefore the flour will be better.* See art. 111.

From these considerations, added to experiments, I conclude, that the power required and quantity ground, will nearer approach to be as the area of the stones, multiplied into the velocity of the mean circles; or, which is nearly the same, as the squares of their diameters. But if the velocities of their mean circles or circumferences be equal, then it will be as their area, simply.

On these principles I have calculated the following table, shewing the power required and quantity ground both by theory and what I suppose to be the nearest practice.

* A French author (M. Fabre) says, that by experiments he has found, that to produce the best flour, a stone 5 feet diameter should revolve between 48 and 61 times in a minute. This is much slower than practice in America, but we may conclude that it is best to err on the side of slower than faster than common practice; especially when the power is too small for the size of the stone.

A TABLE

OF THE

AREA OF MILL-STONES,

OF

DIFFERENT DIAMETERS,

Deducting 1 foot for the eye; and of the power required to move them with a mean velocity of 18 feet per second, &c.

Diameter of the stone in feet and parts.	Area of the stone in feet and parts, deducting 1 foot for the eye.	Power required to drive the stone with mean velocity 18 feet per second, allowing 6 cubchs to each foot of its area.	Circumference of the mean circle to contain half the area of the stone.	Revolutions of the stone per minute, with 18 feet velocity of mean circle	Number of superficial feet passed per minute, being the square of the area of the stones multiplied by the number of revolutions.	Quantity ground in lbs. per minute, or bushels per hour, supposing it to be as the number of superficial feet passed.	Power required supposing it to be as the number of superficial feet passed.	Quantity ground supposing it to be simply as the area of the stone with equal velocity.	Quantity ground supposing it to be as the squares of the diameter of the stone, which appears to come nearest the true quantity.
feet	s. t.	cubs.	feet.		sup ft	lbs.	cubs.	lbs.	lbs.
3,5	8,62	51.72	7,777	138,8	10312	1,49	33,1	2,3	2,45
3.75	9,99	59,94							2,8
4,	11,56	69,36	8,888	121,5	16236	2,3	52	3,1	3,2
4,25	13,18	79,							3,6
4.5	14,9	89,4	9,99	108,1	23999	3,46	77	4,	4,05
4,75	16,71	100,26							4,5
5,	18,63	111,78	11,09	97,4	34804	5,	111,78	5,	5,
5,25	20,64	123,84							5,53
5,5	22,76	136,5							6,05
5,75	24,96	153,7							6.6
6,	27,27	163,6	13,37	80,7	60012	8,6	192	7,3	7,2
6,25	29,67	178,							7,8
6,5	32,18	196,							8,4
6,75	34,77	208,6							9,1
7,	37 48	225,	15,55	69,4	97499	14,06	313	10	9,8
1	2	3	4	5	6	4	8	9	10

Note. The reason why the quantity ground in the 7th column, is not exactly as the cubes of the diameter of the stone, and in the 9th column not exactly as the squares of its diameter, is the deduction for the eye, being equal in each stone, destroys the proportion.

The engine of a paper-mill, roll 2 feet diameter, 2 feet long, revolving 160 times in a minute, requires equal power with a 4 feet stone, grinding 5 bushels an hour.

Having now laid down in art. 61, 62, and 63, a theory for measuring the power of any mill-seat, and for ascertaining the quantity of that power that mill-stones of different diameters will require, by which we can find the diameter of the stones to suit the power of the seat: and having fixed on six cubochs of that power per second to every superficial foot of the mill-stone, as requisite to move the mean circle of the stone 18 feet per second, when in the act of grinding with moderate and sufficient feed, and having allowed the passing of 34804 feet per minute to grind 5lb. in the same time, which is the effect of the five feet stone in the table, by which, if right, we can calculate the quantity that a stone of any size will grind with any velocity.

I have chosen a velocity of 18 feet per second, for the mean circle of all stones, which is slower than common practice, but not too slow for making good flour. See art. 111. Here will appear the advantage of large stones over small ones; for if we will make small stones grind as fast as large ones, we must give them such velocity as to heat the meal.

But I wish to inform the reader, that the experiments, from which I have deduced the quantity of power to each superficial foot to be six cubochs, have not been sufficiently accurate to be relied on; but it will be easy for every ingenious mill-wright to make accurate experiments to satisfy himself as to this.*

* After having published the first edition of this work, I have been informed, that by accurate experiments made at the expense of the British government, it was ascertained that the power produced by 40,000 cubic feet of water descending 1 foot, will grind and bolt 1 bushel of wheat. If this be true, then, to find the quantity that any stream will grind per hour, multiply the cubic feet of water that it affords per hour, by the virtual descent, (that is, half of the head above the wheel added to the fall after it enters an overshot wheel,) and divide that product by 40,000, and the quotient is the answer in bushels per hour that the stream will grind.

EXAMPLE.

Suppose a stream affords 32,000 cubic feet water per hour, and the total fall 19,28 feet; then by the table for overshot mills, art. 73, the wheel should be 16 feet diameter, head above the wheel, 3,28 feet. Then half 3,28=1,64, which added to 16=1764 feet virtual descent, and 17,64× 32000=563480, which divided by 40,000, quotes 14,08 bushels per hour the stream will grind.

ART. 64.

OF CANALS FOR CONVEYING WATER TO MILLS.

In digging canals we must consider that water will come to a level on its surface, be the form of the bottom as it may. If we have once determined on the area of the section of the canal necessary to convey a sufficient quantity of water to the mill, we need only mind to keep to that area in the whole distance, and need not pay much regard to the depth or width, if there be rocks in the way. Much expense may be oftentimes saved, by making the canal deep where it cannot easily be got wide enough, and wide where it cannot easily be got deep enough. Thus, suppose we have determined it to be 4 feet deep, and 6 feet wide, then the area of its section will be 24.—Let fig. 36, plate IV. represent a canal, the line A B the level or surface of the water, C D the side, E F the bottom, A C the width 6 feet, A E the depth 4 feet. Then, if there be rocks at G, so that we cannot without great expense obtain more than 3 feet width, but 8 feet depth at a small expense: then $8\times3=24$, the section required. Again, suppose a flat rock to be at H, so that we cannot, without great expense, obtain more than 2 feet depth, but can, with small expense, obtain 12 feet width: then $2\times12=24$, the section required; and the water will come on equally well, even if it were not more than ,5 of a foot deep, provided it be proportionably wide. One disadvantage however arises in having canals too shallow in places, because the water in dry seasons, may be too low to rise over them; but if the water was always to be of one height, the disadvantage would be but little. The current will keep the deep places open; light sand or mud will not settle in them. This will seem paradoxical to some, but, seeing the experiment may be a saving of expense, it may be worth trying.

ART. 65.

OF THE SIZE AND FALL OF CANALS.

As to the size and fall necessary to convey any quantity of water required to a mill, I do not find any rule laid down for either. But in order to establish one, let us consider, that the size depends entirely upon the quantity of water and the velocity with which it is to pass: therefore, if we can determine on the velocity, which I will suppose to be from 1 to 2 feet per second —but the slower the better, as there will be the less fall lost—we can find the size of the canal by the following

THEOREM.

Divide the quantity required in cubic feet per second, by the velocity in feet per second, and the quotient will be the area of the section of the canal. Divide that area by the proposed depth, and the quotient is the width: or, divide by the width, and the quotient is the depth.

PROBLEM I.

Given, a 5 feet mill-stone to be moved 18 feet per second, velocity of its mean circle on a seat of 10 feet virtual or effective descent, required the size of the canal, with a velocity of 1 foot per second.

Then, by theorem in art. 63: The area of the stone 18,63 feet, multiplied by six cubochs of power, is equal 111,78 cubochs for the power (in common practice say 112 cubochs) which, divided by 10 the fall, quotes 11,178 cubic feet required per second, which, divided by 1, the velocity proposed per second, quotes 11,178 feet, the area of the section, which divided by the depth proposed, two feet, quotes 5,58 feet for the width.

PROBLEM II.

Given, a mill-stone 6 feet diameter, to be moved with a velocity of 18 feet per second of its mean circle, to be turned by an undershot wheel on a seat of 8 feet per-

pendicular descent, required the power necessary per second to drive them, and the quantity of water per second to produce said power, likewise the size of the canal to convey the water with a velocity of 1,5 feet per second.

Then, by art. 61, 8 feet perpendicular descent, on the undershot principle, is only=4 feet virtual or effective descent: and the area of the stone by the table (art. 63) =27,27 feet×6 cubochs=163,62 cubochs, for the power per second, which divided by 4, the effective descent= 40,9 cubic feet, the quantity required per second, which divided by the velocity proposed 1,5 feet per second= 20,45, for the area of the section of the canal, which divided by 2,25 feet, the depth of the canal proposed=9,1 feet, the width.*

As to the fall necessary in the canal, I may observe, that the fall should be in the bottom of the canal and none on the top, which should be all the way on a level with the water in the dam, in order that when the gate is shut down at the mill, the water will not overflow the banks, but stand at a level with the water in the dam; that is, as much fall as there is to be in the whole length of the canal, so much deeper must the canal be at the mill than at the dam. From observations I conclude that about 3 inches to 100 yards will be sufficient, if the canal be long, but more will be better if it be short, and the head apt to run down when water is scarce, for the shallower the water the greater must be the velocity, and more fall is required.—A French author, M. Fabre, allows 1 inch to 500 feet.

* An acre of a mill-pond contains 43560 cubic feet of water, for every foot of its depth.

Suppose your pond contains 3 acres and is 3 feet deep, then 43560, multiplied by 3, is equal 130680, which multiplied by 3, is equal 392040 cubic feet, its contents, which divided by the cubic feet your mill uses per second (say 10) is equal 39204 seconds, or 10 hours, the time the pond will keep the mill going.

ART. 66.

OF AIR-PIPES TO PREVENT TIGHT TRUNKS FROM BURSTING WHEN FILLED WITH WATER

When water is to be conveyed under ground, or in a tight trunk below the surface of the water in the reservoir, to any considerable length, there must be air-pipes (as they have been called) to prevent the trunk from bursting. To understand their use let us suppose a trunk 100 feet long, 16 feet below the surface of the water, to fill which draw a gate at one end of equal size with the trunk. Then the water, in passing to the other end acquires great velocity if it meets no resistance, which velocity is suddenly to be stopped when the trunk is full. This great column of water in motion, in this case, would strike with a force equal to a solid body of equal weight and velocity, the shock of which would be sufficient to burst any trunk that ever was made of wood. Many having thought the use of these pipes to be to let out the air, have made them too small, so that they would vent the air fast enough to let the water in with considerable velocity, but would not vent the water fast enough when full, to check its motion easily, in which case they are worse than none at all, for if the air cannot escape freely, the water cannot enter freely.

Whenever the air has been compressed in the trunk by the water coming in, it has made a great blowing noise in escaping through the crevices, and therefore has been blamed as the cause of the bursting of the trunk; whereas it acted by its elastic principle, as a great preventive against it. For I do suppose, that if we were to pump the air all out of a trunk, 100 feet long, and 3 by 3 feet wide, and let the water in with full force, that it would burst, if as thick as a cannon of cast metal: because in that case there would be 900 cubic feet of water, equal to 56250lbs. pressed on by the weight of the atmosphere, with a velocity of 47 feet per second, to be suddenly stopped, the shock would be inconceivable.

* To prevent ice from gathering on overshot wheels when standing, the water is shut out of the trunk by a gate at the canal, and what leaks through it is let through a hole in the bottom of the trunk; the water is let in again with full force.

Therefore I do conclude it best, to make an air-pipe for every 20 or 30 feet, of the full size of the trunk; but this will depend much on the depth of the trunk below the surface of the reservoir, and many other circumstances.

Having now said what was necessary, in order the better to understand the theory of the power and principles of mechanical engines, and water acting on the different principles on water-wheels, and for the establishing new and true theories of the motion of the different kinds of water-wheels, I here quote many of the ingenious Smeaton's experiments, that the reader may compare them with the theories established, and judge for himself.

ART. 67.

SMEATON'S EXPERIMENTS.

An experimental Enquiry, read in the Philosophical Society in London, May 3d, and 10*th*, 1759, *concerning the Natural Powers of Water to turn Mills and other Machines, depending on a circular motion, by James Smeaton, F. R. S.*

What I have to communicate on this subject was originally deduced from experiments made on working models, which I look upon as the best means of obtaining the outlines in mechanical enquiries. But in this case it is necessary to distinguish the circumstances in which a model differs from a machine in large: otherwise a model is more apt to lead us from the truth than towards it. Hence the common observation, that a thing may do very well in a model that will not do in large. And indeed though the utmost circumspection be used in this way, the best structure of machines cannot be fully ascertained, but by making trials with them of their proper size. It is for this purpose that though the models referred to, and the greatest part of the following experiments, were made in the years 1752, and 1753, yet I deferred offering them to the society till I had an opportunity of putting the deduction made therefrom in

real practice, in a variety of cases and for various purposes, so as to be able to assure the society, that I have found them to answer.

PART I.

CONCERNING UNDERSHOT WATER-WHEELS.

Plate XII. is a view of the machine for experiments, on water-wheels, wherein

ABCD is the lower cistern or magazine for receiving the water after it has left the wheel, and for supplying

DE the upper cistern or head, wherein the water being raised to any height by a pump, that height is shewn by

FG a small rod divided into inches and parts, with a float at the bottom to move the rod up and down, as the surface of the water rises and falls.

HI is a rod by which the sluice is drawn, and stopped at any height required, by means of

K a pin or peg, which fits several holes placed in the manner of a diagonal scale upon the face of the rod HI.

GL is the upper part of the rod of the pump for drawing the water out of the lower cistern, in order to raise and keep up the surface thereof to its desired height in the head DE, thereby to supply the water expended by the aperture of the sluice.

MM is the arch and handle of the pump, which is limited in its stroke by

N a piece for stopping the handle from raising the piston too high, that also being prevented from going too low, by meeting the bottom of the barrel.

O is the cylinder upon which the cord winds, and which being conducted over the pullies P and Q, raises.

R the scale, into which the weights are put for trying the power of the water.

W the beam, which supports the scale that is placed 15 or 16 feet higher than the wheel.

XX is the pump-barrel 5 inches diameter and 11 inches long.

Y is the piston, and

Z is the fixed valve.

GV is a cylinder of wood fixed upon the pump-rod, and reaches above the surface of the water; this piece of wood being of such a thickness that its section is half the area of the pump-barrel, will cause the water to rise in the head as much while the piston is descending as while it is rising, and will thereby keep the gauge-rod FG more equally to its height.

a a shews one of the two wires that serves as a director to the float.

b is the aperture of the sluice.

c a is a cant-board for canting the water down the opening c d into the lower cistern.

c e is a sloping board for bringing back the water that is thrown up by the wheel.

There is a contrivance for engaging and disengaging the scale and weight instantaneously from the wheel, by means of a hollow cylinder on which the cord winds by slipping it on the shaft, and when it is disengaged it is held to its place by a ratchet-wheel, for without this, experiments could not be made with any degree of exactness.

The apparatus being now explained, I think it necessary to assign the sense in which I use the term power.

The word power is used in practical mechanics, I apprehend, to signify the exertion of strength, gravity, impulse, or pressure, so as to produce motion.

The raising of a weight relative to the height, to which it can be raised in a given time, is the most proper measure of power. Or in other words, if the weight raised, is multiplied by the height to which it can be raised in a given time, the product is the measure of the power raising it, and consequently all those powers are equal. But note all this is to be understood in case of slow or equable motion of the body raised, for in quick, accelerated, or retarded motions, the vis inertia of the matter moved will make a variation.

In comparing the effects procuced by water-wheels with the powers producing them; or in other words, to know what part of the original power is necessarily lost in the application, we must previously know how much of the power is spent in overcoming the friction of the

machinery and the resistance of the air, also what is the real velocity of the water at the instant it strikes the wheel, and the real quantity of water expended in a given time.

From the velocity of the water at the instant that it strikes the wheel, given; the height of the head productive of such velocity can be deduced, from acknowledged and experienced principles of hydrostatics: so that by multiplying the quantity or weight of water really expended in a given time, by the height of head so obtained; which must be considered as the height from which that weight of water had descended, in that given time; we shall have a product equal to the original power of the water, and clear of all uncertainty that would arise from the friction of the water in passing small apertures, and from all doubts, arising from the different measure of spouting waters, assigned by different authors.

On the other hand the sum of the weights raised by the action of this water, and of the weight required to overcome the friction and resistance of the machine; multiplied by the height to which the weight can be raised in the time given, the product will be the effect of that power; and the proportion of the two products will be the proportion of the power to the effect: so that by loading the wheel with different weights successively, we shall be able to determine at what particular load and velocity of the wheel the effect is a maximum.

To determine the Velocity of the Water striking the Wheel.

Firt let the wheel be put in motion by the water, but without any weight in the scale; and let the number of turns in a minute be 60: now it is evident, that was the wheel free from friction and resistance, that 60 times the circumference of the wheel would be the space through which the water would have passed in a minute; with that velocily wherewith it struck the wheel: But the wheel being incumbered with friction and resistance, and yet moving 60 turns in a minute, it is plain that the velocity of the water must have been greater than 60 circumferences, before it met with the wheel. Let the

cord now be wound round the cylinder, but contrary to the usual way, and put as much weight in the scale as will without any water turn the wheel somewhat faster than 60 turns in a minute, suppose 63, and call this the counter-weight, then let it be tried again with the water assisted by this counter-weight, the wheel therefore will now make more than 60 turns in a minute, suppose 64, hence we conclude the water still exerts some power to turn the wheel. Let the weight be increased so as to make 64½ turns in a minute without the water, then try it with the water and the weight as before, and suppose it now makes the same number of turns with the water, as without, viz. 64½, hence it is evident, that in this case the wheel makes the same number of turns as it would with the water, if the wheel had no friction or resistance at all, because the weight is equivalent thereto, for if the counter-weight was too little to overcome the friction, the water would accelerate the wheel, and if too great it would retard it, for the water in this case becomes a regulator of the wheel's motion, and the velocity of its circumference becomes a measure of the velocity of the water.

In like manner in seeking the greatest product or maximum of effect; having found by trials what weight gives the greatest product, by simply multiplying the weight in the scale, by the number of turns of the wheel, find what weight in the scale, when the cord is on the contrary side of the cylinder, will cause the wheel to make the same number of turns, the same way without water; it is evident that this weight will be nearly equal to all friction and resistance taken together; and consequently that the weight in the scale, with twice* the weight of the scale, added to the back or counter-weight, will be equal to the weight that could have been raised supposing the machine had been without friction or resistance, and which multiplied by the height to which it was raised, the product will be the greatest effect of that power.

* The weight of the scale makes part of the weight both ways, viz. both of the weight and counter-weight.

The Quantity of Water expended is found thus:

The pump was so carefully made, that no water escaped back through the leathers, it delivered the same quantity each stroke, whether quick or slow, and by ascertaining the quantity of 12 strokes and counting the number of strokes in a minute, that was sufficient to keep the surface of the water to the same height, the quantity expended was found.

These things will be further illustrated by going over the calculations of one set of experiments.

Specimen of a set of experiments.

The sluice drawn to the 1st hole.	
The water above the floor of the sluice	30 inch.
Strokes of the pump in a minute,	39½
The head raised by 12 strokes,	21 inch.
The wheel raised the empty scale and made turns in a minute,	80
With a counter-weight of 1 lb. 8 oz. it made	85
Ditto, tried with water,	86

No.	lbs. oz.	turns in a min.	product.
1	4 : 0	45	180
2	5 : 0	42	210
3	6 : 0	36¼	217½
4	7 : 0	33¾	236¼
5	8 : 0	30	240 max.
6	9 : 0	26½	238½
7	10 : 0	22	220
8	11 : 0	16½	181½
9	12 : 0	* ceased working.	

Counter-weight for 30 turns without water 2 oz. in the scale.

N. B. The area of the head was 105,8 square inches, weight of the empty scale and pulley 10 ounces, circum-

* When the wheel moves so slow as not to rid the water so fast as supplied by the sluice, the accumulated water falls back upon the aperture, and the wheel immediately ceases moving.

Note. This note of the author argues in favour of drawing the gate near the floats.

ference of the cylinder 9 inches, and circumference of the water-wheel 75 inches.

Reduction of the above Set of Experiments.

The circumference of the wheel 75 inches, multiplied by 86 tons, gives 6450 inches for the velocity of the water in a minute, 1-60 of which will be the velocity in a second, equal to 107,5 inches, or 8,96 feet, which is due to a head of 15 inches,* and this we call the virtual or effective head.

The area of the head being 105,8 inches, this multiplied by the weight of water of one cubic inch, is equal to the decimal of ,579 of the ounce avoirdupois, gives 61,26 ounces for the weight of as much water as is contained in the head upon one inch in depth, 1-10 of which is 3,83lb. this multiplied by the depth 21 inches gives 80,43lb. for the value of 12 strokes, and by proportion 39½ (the number made in a minute) will give 264,7lb. the weight of water expended in a minute.

Now as 264,7lb. of water may be considered as having descended through a space of 15 inches in a minute, the product of these two numbers 3970 will express the power of the water to produce mechanical effects; which are as follows.

The velocity of the wheel at a maximum as appears above, was 30 turns in a minute; which multiplied by 9 inches, the circumference of the cylinder, makes 270 inches: but as the scale was hung by a pulley and double line, the weight was only raised half of this, viz. 135 inches,

The weight in the scale at the maximum.	8lb.	0 oz.
Weight of the scale and pulley,	0lb.	10 oz.
Counter-weight, scale, and pulley,	0lb.	12 oz.
Sum of the resistance,	9lb.	6 oz. or 9,375lb.

* This is determined by the common maxim of hydrostatics; that the velocity of spouting water is equal to the velocity that a heavy body would require in falling from the height of the reservoir; and is proved by the rising of jets, to the height of their reservoirs nearly.

Now, as 9,375lb is raised 135 inches, these two numbers being multiplied together produces 1266, which expresses the effect produced at a maximum: so that the proportion of the power to the effect is as 3970 : 1266, or as 10 : 3,18.

But though this is the greatest single effect producible from the power mentioned, by the impulse of the water upon an undershot wheel; yet as the whole power of the water is not exhausted thereby, this will not be the true ratio between the power and the sum of all the effects producible therefrom: for as the water must necessarily leave the wheel with a velocity equal to the circumference, it is plain that some part of the power of the water must remain after leaving the wheel.

The velocity of the wheel at a maximum is 30 turns a minute, and consequently its circumference moves at the rate of 3,123 feet per second, which answers to a head of 1,82 inches: this being multiplied by the expense of water in a minute, viz. 264,7lb. produces 481 for the power remaining, this being deducted from the original power 3970, leaves 3489 which is that part of the power that is spent in producing the effect 1266, so that the power spent 3489 is to its greatest effect 1266, as 10 : 3,62, or as 11 : 4.

The velocity of the water striking the wheel 86 turns in a minute, is to the velocity at a maximum 30 turns a minute, as 10 : 3,5 or as 20 to 7, so that the velocity of the wheel is a little more than 1-3 of the velocity of the water.

The load at a maximum has been shewn to be equal to 9lb. 6oz. and that the wheel ceased moving with 12lb. in the scale: to which if the weight of the scale be added, viz. 10 oz.* the proportion will be nearly as 3 to 4, between the load at a maximum and that by which the wheel is stopped.†

* The resistance of the air in this case ceases, and the friction is not added, as 12 lb. in the scale was sufficient to stop the wheel after it had been in full motion, and therefore somewhat more than a counter-balance for the impulse of the water.

† I may here observe, that it is probable, that if the gate of the sluice had been drawn as near the float-boards as possible, (as is the practice in America, where water is applied to act by impulse alone,) that the wheel

It is somewhat remarkable, that though the velocity of the wheel in relation to the water turns out greater than 1-3 of the velocity of the water, yet the impulse of the water in case of the maximum is more than double of what is assigned by theory; that is, instead of 4-9 of the column, it is nearly equal to the whole column.*

It must be remembered, therefore, that in the present case, the wheel was not placed in an open river where the natural current, after it has communicated its impulse to the float, has room on all sides to escape, as the theory supposes; but in a conduit or race, to which the float being adapted, the water cannot otherwise escape than by moving along with the wheel. It is observable, that a wheel working in this manner, as soon as the water meets the float, it receiving a sudden check, rises up against the float, like a wave against a fixed object, insomuch, that when the sheet of water is not a quarter of an inch thick before it meets the float, yet this sheet will act upon the whole surface of a float, whose height is three inches; consequently, was the float no higher than the thickness of the sheet of water, as the theory also supposes, a great part of the force would be lost by the water dashing over the float.

In confirmation of what is already delivered, I have adjoined the following table, containing the result of 27 experiments made and reduced in the manner above specified. What remains of the theory of undershot wheels, will naturally follow from a comparison of the different experiments together.

would have continued to move until loaded with 1 1-2 times the weight of the maximum load, viz. 9lb. 6 oz. multiplied by 1 1-2, is equal to 14lb. 1 oz. Then it would have agreed with the theory established art. 41. This perhaps escaped the notice of our author.

* This observation of the author I think a strong confirmation of the truths of the theory established art. 41; where the maximum velocity is made to be ,577 parts of the velocity of the water, and the load to be 2-3 the greatest load: For if the gate had been drawn near the floats, the greatest load would probably have been 14lb. 1 oz. or as 3 to 2, of the maximum load.

A TABLE OF EXPERIMENTS,

No. I.

Number.	Height of the water in the cistern.	Turns of the wheel, unloaded.	Virtual head deduced therefrom.	Turns at a maximum.	Load at the equilibrium.	Load at the maximum.	Water expended in a minute.	Power.	Effect.	Ratio of the power and effect.	Ratio of the velocities of the water and wheel.	Ratio of the load at the equilibrium to the load at the maximum.	Experiments.
	in.		inch.		lb. oz.	lb. oz.	lbs.						
1	33	88	15,85	30	13 10	10 9	275	4358	1411	10:3,24	10:3,4	10:7,75	At the 1st hole.
2	30	86	15,	30	12 10	9 6	264,7	3970	1266	10:3,2	10:3,5	10:7,4	
3	27	82	13,7	28	11 2	8 6	243	3329	1044	10:3,15	10:3,4	10:7,5	
4	24	78	12,3	27,7	9 10	7 5	235	2890	901,4	10:3,12	10:3,55	10:7,53	
5	21	75	11,4	25,9	8 10	6 5	214	2439	735,7	10:3,02	10:3,45	10:7,32	
6	18	70	9,95	23,5	6 10	5 5	199	1970	561,8	10:2,85	10:3,36	10:8,02	
7	15	65	8,54	23,4	5 2	4 4	178,5	1524	442,5	10:2,9	10:3,6	10:8,3	
8	12	60	7,29	22	3 10	3 5	161	1173	328	10:2,8	10:3,77	10:9,1	
9	9	52	5,47	19	2 12	2 8	134	733	213,7	10:2,9	10:3,65	10:9,1	
10	6	42	3,55	16	1 12	1 10	114	404,7	117	10:2,82	10:3,8	10:9,3	
11	24	84	14,2	30,75	13 10	10 14	342	4890	1505	10:3,07	10:3,66	10:7,9	At the 2d.
12	21	81	13,5	29	11 10	9 6	297	4009	1223	10:3,01	10:3,62	10:8,05	
13	18	72	10,5	26	9 10	8 7	285	2993	975	10:3,25	10:3,6	10:8,75	
14	15	69	9,6	25	7 10	6 14	277	2659	774	10:2,92	10:3,62	10:9,	
15	12	63	8,0	25	5 10	4 14	234	1872	549	10:2,94	10:3,97	10:8,7	
16	9	56	6,37	23	4 0	3 13	201	1280	390	10:3,05	10:4,1	10:9,5	
17	6	46	4,25	21	2 8	2 4	167,5	712	212	10:2,98	10:4,55	10:9,	
18	15	72	10,5	29	11 10	9 6	357	3748	1201	10:3,23	10:4,02	10:8,05	3d.
19	12	66	8,75	26,75	8 10	7 6	330	2887	878	10:3,05	10:4,05	10:8,1	
20	9	58	6,8	24,5	5 8	5 0	255	1734	541	10:3,01	10:4,22	10:9,1	
21	6	48	4,7	23,5	3 2	3 0	228	1064	317	10:2,99	10:4,9	10:9,6	
22	12	68	9,3	27	9 2	8 6	359	3338	1006	10:3,02	10:3,97	10:9,17	4th.
23	9	58	6,8	26,25	6 2	5 13	332	2257	686	10:3,04	10:4,52	10:9,5	
24	6	48	4,7	24,5	3 12	3 8	262	1231	385	10:3,13	10:5,1	10:9,35	
25	9	60	7,29	27,3	6 12	6 6	355	2588	783	10:3,03	10:4,55	10:9,45	5th.
26	6	50	5,03	24,6	4 6	4 1	307	1544	456	10:2,92	10:4,9	10:9,3	
27	6	50	5,03	26	4 15	4 9	360	1811	534	10:2,95	10:5,2	10:9,25	6.
1	2	3	4	5	6	7	8	9	10	11	12	13	

Maxims and Observations deduced from the foregoing Table of Experiments.

Max. 1. That the virtual or effective head being the same, the effect will be nearly as the quantity of water expended.

This will appear by comparing the contents of the columns 4, 8 and 10, in the foregoing sets of experiments, as for

Example I. taken from No 8 *and* 25, *viz.*

No.	Virtual head.	Water expended.	Effect.
8	7,29	161	328
25	7,29	355	785

Now the heads being equal, if the effects are proportioned to the water expended, we shall have by maxim I. as 161 : 355 :: 328 : 723; but 723 falls short of 785, as it turns out in experiment, according to No. 25 by 62. The effect therefore of No. 25, compared with No 8, is greater than, according to the present maxim, in the ratio of 14 to 13.*

The foregoing example with four similar ones are seen at one view in the foregoing table.

* If the true maximum velocity of the wheel be ,577 of the velocity of the water, and the true maximum load be 2-3 of the whole column, as shewn in art. 42; then the effect will be the power in the ratio of 100 to 38, or as 10 to 3,8, a little more than appears by the table of experiments, in columns 9 and 10: the difference is owing to the disadvantageous application of the water on the wheel in the model.

A TABLE OF EXPERIMENTS,

No. II.

Examples.	No. Table I.	Virtual head.	Expense of water.	Effect.	COMPARISON.	Variation.	Proportional variation.
1st	8 25	7,29 7,29	161 355	328 785	161 : 355 :: 328 : 723	62+	14 : 13
2d	13 18	10,5 10,5	285 357	975 1210	285 : 357 :: 975 : 1221	11—	121 : 122
3d	22 23	6,8 6,8	255 332	541 686	255 : 332 :: 541 : 704	18—	38 : 39
4th	21 24	4,7 4,7	228 262	317 385	228 : 262 :: 317 : 364	21+	18 : 17
5th	26 27	5,03 5,03	307 360	450 534	307 : 360 :: 450 : 531	3+	178 : 177

By this table of experiments it appears that some fall short and others exceed the maximum, and all agree as near as can be expected in an affair where so many different circumstances are concerned; therefore we may conclude the maxim to be true.

Max. II. That the expense of the water being the same, the effect will be nearly as the height of the virtual or effective head.

This also will appear by comparing the contents of columns 4, 8 and 10, in any of the sets of experiments.

Example I. of No. 2 and No. 24.

No.	Virtual head.	Expense.	Effect.
2	15	264,7	1266
24	4,7	262	385

Now as the expenses are not quite equal, we must proportion one of the effects accordingly, thus:

By maxim I. 262 : 264,7 :: 385 : 389
And by max. II. 15 : 4,7 :: 1266 : 397

Difference, 8

The effect therefore of No. 24, compared with No. 2, is less than, according to the present maxim, in the ratio of 49 : 50.

Max. III. That the quantity of water expended being the same, the effect is nearly as the square root of its velocity.

This will appear by comparing the contents of columns 3, 8 and 10, in any set of experiments; as for

Example I. of No. 2 with No. 24, viz.

No.	Turns in a minute.	Expense.	Effect.
2	86	264,7	1266
24	48	262,	385

The velocity being as the number of turns, we shall have

By maxim I.	262 : 264,7	:: 385 : 389
And by max. III.	$\left\{ \begin{array}{c} 86^2 \quad 48^2 \\ 7396 : 2304 \end{array} \right\}$	:: 1266 : 394
	Difference,	5

The effect of No. 24, compared with No. 2, is less than by the present maxim in the ratio of 78 : 79.

Max. IV. The aperture being the same, the effect will be nearly as the cube of the velocity of the water.

This also will appear by comparing the contents of columns 3, 8 and 10, as for

Example of No. 1, *and No.* 10, *viz.*

No.	Turns.	Expense.	Effect.
1	88	275	1411
10	42	114	117

Lemma. It must here be observed, that, if water passes out of an aperture in the same section, but with different velocities, the expense will be proportional to the velocity; and therefore conversely, if the expense is not proportional to the velocity, the section of water is not the same.

Now comparing the water discharged with the turns of No. 1 and 10, we shall have 88 : 42 :: 275 : 131,2; but the water discharged by No. 10 is only 114lb. therefore, though the sluce was drawn to the same height in No. 10 as in No. 1: yet the section of the water passing out, was less in No. 10 than No 1, in the proportion of 114 to 131,2, consequently had the effective aperture or section of the water been the same in No. 10 as in No 1, so that 131,2lb. of water had been discharged, instead of 114lb. the effect would have been increased in the same proportion; that is,

By lemma	88 : 42	:: 275 : 131,2
By maxim I.	114 : 131,2	:: 117 : 134,5
And by max. IV.	$\left\{ \begin{array}{c} 88^3 : 42^3 \\ 681472 : 74088 \end{array} \right\}$	:: 1411 : 153,5
	Difference	19

The effect therefore of No. 10, compared with No. 1, is less than ought to be, by the present maxim, in the ratio of 7:8.

OBSERVATIONS.

Observ. 1st. On comparing columns 2 and 4, table I. it is evident, that the virtual head bears no certain proportion to the head of water, but that when the aperture is greater, or the velocity of the water issuing therefrom less, they approach nearer to a coincidence: and consequently in the large opening of mills and sluices, where great quantities of water are discharged from moderate heads, the head of water and virtual head determined from the velocity will nearer agree, as experience confirms.

Observ. 2nd. Upon comparing the several proportions between the powers and effects in column 11th, the most general is that of 10 to 3; the extremes are 10 to 3,2 and 10 to 2,8; but as it is observable, that where the quantity of water or the velocity thereof is great, that is, where the power is greatest, the 2nd term of the ratio is greatest also, we may therefore well allow the proportion subsisting in large works as 3 to 1.

Observ. 3rd. The proportion of velocities between the water and wheel in column 12 are contained in the limits of 3 to 1 and 2 to 1; but as the greater velocities approach the limits of 3 to 1, and the greater quantity of water approach to that of 2 to 1, the best general proportion will be that of 5 to 2.*

Observ. 4th. On comparing the numbers in column 13, it appears, that there is no certain ratio between the

* I may here observe, that our friend Smeaton may be wrong in his conclusion, that the best general ratio of the velocity of the water to that of the wheel will be as 5 to 2; because, we may observe, that in the first experiment, where the virtual head was 15,85 inches, and the gate drawn to the 1st hole, the ratio is as 10 : 3,4. But in the last experiment, where the head was 5,03 inches, and gate drawn to the 6th hole, the ratio is as 10 : 5,2; and that the 2nd term of the ratio increases gradually, as the head decreases, and quantity of water increases; therefore we may conclude, that in the large openings of mills, that the ratio may approach to 3 to 2; which will agree with the practice and experiments of many able millwrights, of America, and many experiments I have made on mills. And as it is better to give the wheel a velocity too great than too slow, I conclude, the wheel of an undershot mill must have nearly 2-3d of the velocity of the water to produce a maximum effect.

load that the wheel will carry at its maximum, and what will totally stop it; but that they are contained within the limits of 20 to 19 and of 20 to 15; but as the effect approaches nearest to the ratio of 20 to 15 or of 4 to 3, when the power is greatest, whether by increase of velocity or quantity of water, this seems to be the most applicable to large works: but as the load that a wheel ought to have in order to work to the best advantage, can be assigned by knowing the effect it ought to produce, and the velocity it ought to have in producing it, the exact knowledge of the greatest load that it will bear is of less consequence in practice.*

It is to be noted, that in almost all of the examples under the three last maxims (of the four preceding) the effect of the lesser power falls short of its due proportion to the greater, when compared by its maxim. And hence, if the experiments are taken strictly, we must infer that the effects increase and diminish in an higher ratio than those maxims suppose; but as the deviations are not very considerable, the greatest being about 1-8 of the quantity in question, and as it is not easy to make experiments of so compound a nature with absolute precision, we may rather suppose that the lesser power is attended with some friction, or works under some disadvantage, not accounted for: and therefore we may conclude, that these maxims will hold very nearly, when applied to works in large.

After the experiments above-mentioned were tried, the wheel which had 24 floats was reduced to 12, which caused a diminution in the effect on account of a greater quantity of water escaping between the floats and the floor, but a circular sweep being adapted thereto, of such a length that one float entered the curve before the preceding one quitted it, the effect came so near to the former, as not to give hopes of increasing the effect by increasing the number of floats past 24, in this particular wheel.

* Perhaps the author is here again deceived by the imperfection of the model; for had the water been drawn close to the float, the load that would totally stop the wheel would always be equal to the column of water acting on the wheel. See the note page 70. The friction of the shute and air destroyed great part of the force of his small quantity of water.

ART. 68.

PART II.

CONCERNING OVERSHOT WHEELS.

In the former part of this essay, we have considered the impulse of a confined stream, acting on undershot wheels; we now proceed to examine the power and application of water, when acting by its gravity on overshot wheels.

It will appear in the course of the following deductions, that the effect of the gravity of descending bodies, is very different from the effect of the stroke of such as are non-elastic, though generated by an equal mechanical power.

The alterations of the machinery already described, to accommodate the same for experiments on overshot wheels, were principally as follow.

Plate XII. The sluice I b being shut down, the rod H I was taken off. The undershot water-wheel was taken off the axis, and instead thereof, an overshot wheel of the same size and diameter was put in its place. Note, this wheel was 2 inches deep in the shroud or depth of the bucket, the number of buckets was 36.

A trunk for bringing the water upon the wheel was fixed according to the dotted lines f g, the aperture was adjusted by a shuttle which also closed up the outer end of the trunk, when the water was to be stopped.

Specimen of a Set of Experiments.

Head 6 inches—14½ strokes of the pump in a minute, 12 ditto=80lb.* weight of the scale (being wet) 10½ ounces.

Counter-weight for 20 turns besides the scale, 3 ounces.

No.	wt. in the scale.	turns.	product.	observations.
1	0	60	——	threw most part of the water out of the wheel.
2	1	56	——	
3	2	52	——	
4	3	49	147	received the water more quietly.
5	4	47	188	
6	5	45	225	
7	6	42½	255	
8	7	41	287	
9	8	38½	308	
10	9	36½	328½	
11	10	35½	355	
12	11	32¾	360½	
13	12	31¼	375	
14	13	28½	370½	
15	14	27½	385	
16	15	26	390	
17	16	24½	392	
18	17	22¾	386¾	
19	18	21¾	391½	
20	19	20¾	394¼	maximum.
21	20	19¾	395	
22	21	18¼	383¼	
23	22	18	396	worked irregular.
24	23	overset by its load.		

* The small difference in the value of 12 strokes of the pump from the former experiments, was owing to a small difference in the length of the stroke, occasioned by the warping of the wood.

Reduction of the preceding Specimen.

In these experiments the head being 6 inches, and the height of the wheel 24 inches, the whole descent will be 30 inches: the expense of water was 14½ strokes of the pump in a minute, whereof 12 contained 80lb. therefore the water expended in a minute, was 96 2-3lb. which multiplied by 30 inches, gives the power=2900.

If we take the 20th experiment for the maximum, we shall have 20¾ turns in a minute, each of which raised the weight 4½ inches, that is, 93.37 inches in a minute. The weight in the scale was 19lbs. the weight of the scale 10½ oz. the counter-weight 3 oz. in the scale, which, with the weight of the scale 10½ oz. makes in the whole 20½lb. which is the whole resistance or load, this multiplied by 93,37, makes 1914 for the effect.

The ratio therefore of the power and effect will be as 2900:1914, or as 10:6,6, or as 3 to 2 nearly.

But if we compute the power from the height of the wheel only, we have 96 2-3lb. ×24 inches=2320 for the power, and this will be to the effect as 2320:1914 or as 10:8,2, or as 5 to 4 nearly.

The reduction of this specimen is set down in No. 9 of the following table, and the rest were deducted from a similar set of experiments, deduced in the same manner.

TABLE III.

CONTAINING THE RESULT OF 16 SETS OF EXPERIMENTS ON OVERSHOT WHEELS.

Number.	Whole descent	Water expended per minute.	Turns at a maximum per minute.	Weight raised at a maximum.	Power of the whole descent.	Power of the wheel.	Effect.	Ratio of the whole power and effect.	Ratio of the power of the wheel and effect.	Mean ratio.
	inchs	l b		lbs.						
1	27	30	19	6 1-2	810	720	0556	10 : 6,9	10 : 7,7	Medium 10 : 8,1
2	27	56 2-3	16 1-4	14 1-2	1530	1360	1060	10 : 6,9	10 : 7,8	
3	27	56 2-3	20 3 4	12 1-2	1530	1360	1167	10 : 7,6	10 : 8,4	
4	27	63 1-3	20 1-2	13 1-2	1710	1524	1245	10 : 7,3	10 : 8,2	
5	27	76 2-3	21 1 2	15 1-2	2070	1840	1500	10 : 7,3	10 : 8,2	
6	28 1 2	73 1-3	18 3-4	17 1-2	2090	1764	1476	10 : 7	10 : 8,4	10 : 8,2
7	28 1-2	96 2-3	20 1-4	20 1 2	2755	2320	1868	10 : 6,8	10 : 8,1	
8	30	90	20	19 1-2	2700	2160	1755	10 : 6.5	10 : 8,1	10 : 8,2
9	30	96 2-3	20 3-4	20 1-2	2900	2320	1914	10 : 6,6	10 : 8,2	
10	30	113 1-3	21	23 1-2	3400	2720	2221	10 : 6,5	10 : 8,2	
11	33	56 2-3	20 1-4	13 1-2	1870	1360	1230	10 : 6,6	10 : 8	10 : 8,5
12	33	106 2-3	22 1-4	21 1-2	3520	2560	2153	10 : 6,1	10 : '4	
13	33	146 2-3	23	27 1-2	4840	3520	2846	10 : 5,9	10 : 8'1	
14	35	65	19 3-4	16 1-2	2275	1560	1466	10 : 6,5	10 : 9,4	10 : 8,5
15	35	120	21 1-2	25 1-2	4200	2880	2467	10 : 5,9	10 : 8,6	
16	35	163 1-2	25	26 1-2	5728	3924	2981	10 : 5,[illegible]	10 : 7.6	
1	2	3	4	5	6	7	8	9	10	11

OBSERVATIONS AND DEDUCTIONS FROM THE FOREGOING EXPERIMENTS.

I. *Concerning the Ratio between the Power and Effect of Overshot Wheels.*

The effective power of the water must be reckoned upon the whole descent, because it must be raised to that height in order to be in a condition of producing the same effect a second time.

The ratios between the powers so estimated, and the effects at a maximum deduced from the several sets of experiments, are exhibited at one view in column 9 of table III; and hence it appears, that those ratios differ from that of 10 to 7,6 to that of 10 to 5,2; that is, nearly from 4 to 3 to 4:2. In those experiments, where the heads of water and quantities expended are least, the proportion is nearly as 4 to 3; but where the heads and quantities are greatest, it approaches nearer to that of 4 to 2, and by a medium of the whole the ratio is that of 3:2 nearly. We have seen before in our observations upon the effects of undershot wheels, that the general ratio of the power to the effect, when greatest, was as 3:1. The effect, therefore, of overshot wheels, under the same circumstances of quantity and fall, is at a medium double to that of the undershot: and a consequence thereof, that non-elastic bodies when acting by their impulse or collision, communicate only a part of their original power: the other part being spent in changing their figure in consequence of the stroke.*

The powers of water computed from the height of the wheel only, compared with the effects as in column 10, appear to observe a more constant ratio: for if we take the medium of each class, which is set down in column 11, we shall find the extreme to differ no more than from the ratio of 10:8,1 to that of 10:8,5, and as the second term of the ratio gradually increases from 8,1 to 8,5 by an increase of head from 3 inches to 11, the ex-

* These observations of the author agree with the theory, art. 41—42. I may add, that non-elastic bodies, when acting by impulse or collision, communicate only half of their original power, by the laws of motion.

cess of 8,5 above 8,1 is to be imputed to the superior impulse of the water, at the head of 11 inches above that of 3 inches, so that if we reduce 8,1 to 8, on account of the impulse of the 3 inch head, we shall have the ratio of the power computed upon the height of the wheel only, to the effect at a maximum, as 10:8 or as 5:4 nearly. And from the equality of the ratio, between power and effect, subsisting where the constructions are similar, we must infer that the effects as well as the powers, are as the quantities of water and perpendicular heights, multiplied together respectively.

II. *Concerning the most proper Height of the Wheel in Proportion to the whole descent.*

We have already seen in the preceding observation, that the effect of the same quantity of water, descending through the same perpendicular space, is double, when acting by its gravity upon an overshot wheel, to what the same produces when acting by its impulse, upon an undershot. It also appears, that by increasing the head from 3 to 11 inches, that is, the whole descent, from 27 to 35, or in the ratio of 7 to 9 nearly, the effect is advanced no more than in the ratio of 8,1 to 8,4; that is, as 7:7,26, and consequently the increase of the effect is not 1-7 of the increase of the perpendicular height. Hence, it follows, that the higher the wheel is in proportion to the whole descent, the greater will be the effect; because it depends less upon the impulse of the head, and more upon the gravity of the water in the buckets: and if we consider how obliquely the water issuing from the head must strike the buckets, we shall not be at a loss to account for the little advantage that arises from the impulse thereof; and shall immediately see of how little consequence this impulse is to the effect of an overshot wheel. However, as every thing has its limits, so has this: for thus much is desirable, that the water should have somewhat greater velocity, than the circumference of the wheel, in coming thereon: otherwise the wheel will not only be retarded by the buckets striking the water, but thereby dashing a part of it over: so much of the power is lost.

The velocity that the circumference of the wheel ought to have being known, the head requisite to give the water its proper velocity is easily found, by the common rules of hydrostatics, and will be found much less than what is commonly practised.

III. *Concerning the Velocity of the circumference of the Wheel in order to produce the greatest effect.*

If a body is let fall freely from the surface of the head to the bottom of the descent, it will take a certain time in falling; and in this case the whole action of gravity is spent in giving the body a certain velocity: But, if this body in falling is made to act upon some other body, so as to produce a mechanical effect, the falling body will be retarded; because, a part of the action of gravity is then spent in producing the effect, and the remainder only giving motion to the falling body: and, therefore, the slower a body descends, the greater will be the portion of the action of gravity applicable to the producing a mechanical effect. Hence we are led to this general rule, that the less the velocity of the wheel, the greater will be the effect thereof. A confirmation of this doctrine, together with the limits it is subject to in practice, may be deduced from the foregoing specimen of a set of experiments.

From these experiments it appears, that when the wheel made about 20 turns in a minute, the effect was nearly upon the greatest; when it made 30 turns, the effect was diminished about 1-20 part; but, that when it made 40, it was diminished about $\frac{1}{4}$: when it made less than $18\frac{1}{4}$, its motion was irregular; and when it was loaded so as not to admit its making 18 turns, the wheel was overpowered by its load.

It is an advantage in practice, that the velocity of the wheel should not be diminished farther than what will procure some solid advantage in point of power; because, as the motion is slower, the buckets must be made larger; and the wheel being more loaded with water, the stress upon every part of the work will be increased in proportion: the best velocity for practice, therefore, will be such as when the wheel here used

made about 30 turns in a minute; that is, when the velocity of the circumference is a little more than 3 feet in a second.

Experience confirms, that this velocity of 3 feet in a second, is applicable to the highest overshot wheels as well as the lowest; and all other parts of the work being properly adapted thereto, will produce very nearly the greatest effect possible. However, this also is certain, from experience, that high wheels may deviate further from this rule, before they will lose their power, by a given aliquot part of the whole, than low ones can be admitted to do; for a wheel of 24 feet high may move at the rate of 6 feet per second without losing any considerable part of its power: and, on the other hand, I have seen a wheel of 33 feet high that has moved very steadily and well, with a velocity but little exceeding 2 feet.*

[Said Smeaton has also made a model of a wind-mill, and a complete set of experiments on the power and effect of the wind, acting on wind-mill sails of different constructions. But as the accounts thereof are quite too long for the compass of my work, I therefore only extract little more than a few of the principal maxims deduced from his experiments, which, I think, may not only be of good service to those who are concerned in building wind-mills, but may serve to confirm some principles deduced from his experiments on water-mills.]

ART. 69.

PART III.

ON THE CONSTRUCTION AND EFFECTS OF WIND-MILL SAILS.†

In trying experiments on wind-mill sails, the wind itself is too uncertain to answer the purpose; we must therefore have recourse to artificial wind.

* Probably this wheel was working a forge or furnace bellows, which have deceived many by their slow regular motion.

† Read May 31st and June 14th, 1759, in the Philosophical Society of London.

This may be done two ways; either by causing the air to move against the machine, or the machine to move against the air. To cause the air to move against the machine in a sufficient column, with steadiness and the requisite velocity, is not easily put in practice: To carry the machine forward in a right line against the air, would require a larger room than I could conveniently meet with. What I found most practicable, therefore, was to carry the axis whereon the sails were to be fixed progressively round in the circumference of a large circle. Upon this idea the machine was constructed.*

Specimen of a Set of Experiments.

Radius of the sails, - - - -	21 inches
Length of do. in cloth, - - -	18
Breadth of do. - - - -	5,6
† Angle at the extremity, - -	10 degs.
† Do. at the greatest inclination, -	25
† 20 turns of the sails raised the weight,	11,3 inch.
Velocity of the centre of the sails in the circumference of the great circle in a second, in which the machine was carried round,	6 feet.
Continuance of the experiment, .	52 seconds

No.	Weight in the scale.	Turns.	Product.
1	0lb.	108	0
2	6	85	510
3	6½	81	526½
4	7	78	546
5	7½	73	547½ maxim.
6	8	65	520
7	9	0	0

The product is found by simply multiplying the weight in the scale by the number of turns.

* I decline giving any description or draught of this machine, as I have not room; but I may say, that it was constructed so as to wind up a weight, (as did the other model) in order to find the effect of the power. I may also insert a specimen of a set of experiments, which I fear will not be well understood for want of a full explanation of the machine.

† In the following experiments, the angle of the sail is accounted from the plain of their motion; that is, when they stand at right angles to the axis, their angle is denoted ° deg.; this notation being agreeable to the language of practitioners, who call the angle so denoted the weather of the sail; which they denominate greater or less, according to the quantity of the angle.

By this set of experiments it appears, that the maximum velocity is 2·3 of the greatest velocity, and that the ratio of the greatest load to that of a maximum is, as 9 to 7,5, but by adding the weight of the scale and friction to the load, the ratio turns out to be as 10 : 8,4, or as 5 to 4, nearly. The following table is the result of 19 similar sets of experiments.

By the following table it appears, that the most general ratio between the velocity of the sails unloaded and when loaded to a maximum, is 3 to 2, nearly.

And the ratio between the greatest load and the load at a maximum (taking such experiments where the sails answered best), is at a medium about as 6 to 5, nearly.

And that the kind of sails used in the 15th and 16th experiments are best of all, because they produce the greatest effect or product, in proportion to their quantity of surface, as appears in column 12.

TABLE IV.

Containing Nineteen Sets of Experiments on Wind-mill Sails of various Structures, Positions, and Quantities of Surface.

The kind of sails made use of.	Number	Angle at the extremities	Greatest angle	Turns of the sails, unloaded.	Turns at a maximum	Load at a maximum	Greatest load	Product	Quantity of surface	Ratio of the greatest velocity to the velocity at a maximum.	Ratio of the greatest load to the load at a maximum.	Ratio of a surface to the product.
		0	0			lb.	lb.		sq.in			
I	1	35	35	66	42	7,56	12,59	318	404	10:7	10:6	10: 7, 9
II.	2	12	12		70	6,3	7,56	441	404		10:8,3	10:10, 1
	3	15	15	105	69	6,72	8,12	464	404	10:6,6	10:8,3	10:10,15
	4	18	18	96	66	7,0	9,81	462	404	10:7	10:7,1	10:10,15
III.	5	9	26,5		66	7,0		462	404			10:11, 4
	6	12	29,5		70,5	7,35		518	404			10:12, 8
	7	15	32,5		63,5	8,3		527	404			10:13, 0
IV.	8	0	15	120	93	4,75	5,31	442	404	10:7,7	10:8,9	10:11, 0
	9	3	18	120	79	7,0	8.12	553	404	10:6,6	10:8.6	10:13, 7
	10	5	20		78	7,5	8,12	585	404		10:9,2	10:14. 5
	11	7,5	22,5	113	77	8,3	9,81	639	404	10:6,8	10:8 5	10:15, 8
	12	10	25	108	73	8.69	10,37	634	404	10:6,8	10:8,4	10:15, 7
	13	12	27	100.	66	8 41	10,94	580	404	10.6,6	10:7,7	10:14, 4
V.	14	7,5	22,5	123	75	10,65	12,59	799	505	10:6,1	10:8,5	10:15. 8
	15	10	25	117	74	11,08	13,69	820	505	10:6 3	10:8,1	10:16, 2
	16	12	27	114	66	12,09	14,23	799	505	10:5,8	10.8,4	10:15, 8
	17	15	30	96	63	12,09	14,78	762	505	10:6,6	10:8,2	10:15, 1
VI.	18	12	22	105	64,5	16,42	27,87	1059	854	10:6,1	10:5,9	10:12, 4
	19	12	22	99	64,5	18,06		1165	1146	10:5,9		10:10, 1
	1	2	3	4	5	6	7	8	9	10	11	12

I. Plain sails at an angle of 55 degrees.
II. Plain sails weathered according to common practice.
III. Weathered according to Maclaurin's theorem.
IV. Weathered in the Dutch manner, tried in various positions.
V. Weathered in the Dutch manner, but enlarged towards the extremities.
VI. 8 sails, being sectors of ellipses in their best positions.

TABLE V.

Containing the Result of 6 Sets of Experiments, made for determining the difference of Effect according to the difference of the Wind.

Ratio of the greatest load to the load at a maximum.		10 : 8,3 10 : 9,1		10 : 8,5 10 : 8,7	14
Ratio of the greatest velocity to the velocity at a maximum.		10 : 6,9 10 : 5,9		10 : 6,7 10 · 6,2	13
Ratio of the two products		10:27,3	10:27,8	10:26	12
Product of the lesser load and greater velocity.		805	832	795	11
Turns of the sails therewith . . .		180	180	158	10
Maximum load for the half velocity.		4,47	4,62	5,03	9
Product		295 2003	300 2278	307 2047	8
Greatest load	lbs.	5,37 18,06		5,87 21,34	7
Load at the maximum	lbs.	4,47 16,42	4.62 17,52	5.03 18.61	6
Turns of the sails at a maximum .		66 122	65 130	61 110	5
Turns of the sails, unloaded . . .		96 207		91 178	4
Velocity of the wind in a second .	ft. in.	4 4,5 8 9	4 4,5 8 9	4 4,5 8 9	3
Angle at the extremity	degr.	5 5	7,5 7,5	10 10	2
Number		1 2	3 4	5 6	1

N B. The sails were the same kind as those of Nos. 10, 11 and 12, table IV. Continuance of the experiment one minute.

Concerning the Effects of Sails according to the different Velocity of the Wind.

From the foregoing table the following maxims are deduced.

Maxim I. The velocity of wind-mill sails, whether unloaded or loaded, so as to produce a maximum, is nearly as the velocity of the wind, their shape and position being the same.

This appears by comparing the respective numbers of columns 4 and 5, table V, wherein those numbers 2, 4 and 6, ought to be double of No. 1, 3 and 5, and are as nearly so as can be expected by the experiments.

Maxim II. The load at the maximum is nearly but somewhat less than as the square of the velocity of the wind, the shape and position of the sails being the same.

This appears by comparing No. 2, 4 and 6, in column 6, with 1, 3 and 5, wherein the former ought to be quadruple of the latter (as the velocity is double) and are as nearly so as can be expected.

Maxim III. The effects of the same sails at a maximum are nearly, but somewhat less than, as the cubes of the velocity of the wind.*

It has been shewn, maxim I, that the velocity of sails at a maximum, is nearly as the velocity of the wind; and by maxim II, that the load at the maximum is nearly as the square of the same velocity. If those two maxims would hold precisely, it would be a consequence that the effect would be in a triplicate ratio thereof. How this agrees with experiment will appear by comparing the products in column 8, wherein those of No. 2, 4 and 6 (the velocity of the wind being double) ought to be octuble of those of No. 1, 3 and 5, and are nearly so.

Maxim. IV. The load of the same sails at the maximum is nearly as the squares of, and their effects as the cubes of, their number of turns in a given time.

This maxim may be esteemed a consequence of the hree preceding ones.

* This confirms the 7th law of spouting fluids.

[These 4 maxims agree with and confirm the 4 maxims concerning the effects of spouting fluids acting on undershot mills; and, I think, sufficiently confirms as a law of motion, that the effect produced, if not the instant momentum of a body in motion, is as the square of its velocity, as asserted by the Dutch and Italian philosophers.

Smeaton says, that by several trials in large, he has found the following angles to answer as well as any :] The radius is supposed to be divided into 6 parts, and 1-6 reckoning from the centre is called 1, the extremity being denoted 6.

No.	Angle with the axis.	Angle with the plain of motion.
1	72°	18°
2	71	19
3	72	18 middle.
4	74	16
5	77½	12½
6	83	7 extremity.

[He seems to prefer the sails being largest at the extremities.]

END OF PART FIRST

PART II.

THE YOUNG

MILL-WRIGHT'S GUIDE.

INTRODUCTION.

WHAT has been said in the first part, was meant to establish theories and easy rules. In this part I mean to bring them into practice, in as concise a manner as possible, referring only to the articles in the first part, where the reasons and demonstrations are given.

This part is particularly intended for the help of young and practical mill-wrights, whose time will not permit them fully to investigate the principles of theories, which require a longer series of studies than most of them can possibly spare from their business; therefore I shall endeavour here to reduce the substance of all that has been said, to a few tables, rules, and short directions, which, if found to agree with practice, will be sufficient for the practitioner.

There are but two principles by which water acts on mill-wheels, to give them motion, viz. Percussion and Gravity.

That equal quantities of water, under equal perpendicular descents, will produce double the power by gravity that they will by percussion, has been shown in articles 8 and 68.

Therefore, when the water is scarce, we ought to endeavour to cause it to act by gravity as much as possible, paying due regard to other circumstances noted in article 44, so as to obtain a steady motion, &c.

THE

YOUNG MILL-WRIGHT'S

GUIDE.

PART THE SECOND.

CHAPTER I.

OF THE DIFFERENT KINDS OF MILLS.

ARTICLE 70.

OF UNDERSHOT MILLS.

UNDERSHOT wheels move by the percussion or stroke of the water, and are only half as powerful as other wheels that are moved by the gravity of the water. See art. 8. Therefore this construction ought not to be used, except where there is but little fall or great plenty of water. The undershot wheel, and all others that move by percussion, should move with a velocity nearly equal to two-thirds of the velocity of the water. See art. 42. Fig. 28, plate IV. represents this construction.

For a rule for finding the velocity of the water, under any given head, see art. 51.

Upon which principles, and by said rule, is formed the following table of the velocity of spouting water, under different heads, from one to twenty-five feet high above the centre of the issue; to which is added the velocity of the wheel suitable thereto, and the number of revolutions a wheel of fifteen feet diameter (which I take to be a good size) will revolve in a minute; also,

the number of cogs and rounds in the wheels, both for double and single gears, so as to produce about ninety-seven or one hundred revolutions for a five feet stone per minute, which I take to be a good motion and size for a mill-stone, grinding for merchantable flour.

That the reader may fully understand how the following table is calculated, let him observe,

1. That by art. 42, the velocity of the wheel must be just 577 thousandth parts of the velocity of the water; therefore if the velocity of the water, per second, be multiplied by ,577 the product will be the maximum velocity of the wheel, or velocity that will produce the greatest effect, which is the third column in the table.

2. The velocity of the wheel per second, multiplied by 60, produces the distance the circumference moves per minute, which divided by 47,1 feet, the circumference of a 15 feet wheel, quotes the number of revolutions of the wheel per minute, which is the fourth column.

3. That by art. 20 and 74, the number of revolutions of the wheel per minute, multiplied by the number of cogs in all the driving wheels, successively, and that product divided by the product of the number of cogs in all the leading wheels, multiplied successively, the quotient is the revolutions of the stones per minute, which is the ninth and twelfth columns.

4. The cubochs of power required to drive the stone, being, by art. 61, equal to 111,78 cubochs per second, which, divided by half the head of water, added to all the fall (if any), being the virtual or effective head by art. 61, quotes the quantity of water, in cubic feet, required per second, which is the thirteenth column.

5. The quantity required, divided by the velocity with which it is to issue, quotes the area of the aperture of the gate—fourteenth column.

6. The quantity required, divided by the velocity of the water proper for it to move along the canal, quotes the area of the section of the canal—fifteenth column.

7. Having obtained their areas, it is easy, by art. 65, to determine the width and depth, as may suit other circumstances.

THE MILLWRIGHT'S TABLE

FOR

UNDERSHOT MILLS,

CALCULATED FOR A WATER-WHEEL OF FIFTEEN FEET, AND STONES OF FIVE FEET DIAMETER.

Head of water above the point of impact.	Velocity of the water per second at the point of impact.	Velocity of the wheel per second, loaded at a maximum.	Number of revolutions of the wheel of 15 feet diameter, per minute.	No. of cogs in the master cog-wheel.	Rounds in the wallower.	Cogs in the counter cog-wheel.	Rounds in the trundle.	Revolutions of the stone per minute.	Cogs in the cog-wheel for single gear.	Rounds in the trundle.	Revolutions of the stone per minute.	Cubic feet of water required per second to drive a 5 feet stone 97 revolutions per minute.	Area of the gate to vent the water, or rather of a section of the column of water at place of impact.	Area of a section of the canal sufficient to bring on the water with 1,5 feet velocity.
feet.	feet.	feet.										cub. ft.	sup. ft.	sup. ft.
1	8,1	4,67	5,94	112	22	54	16	101,6				223,5	27,5	149,
2	11,4	6,57	8,36	96	23	54	19	99,				111,78	9.8	74,5
3	14,	8,07	10,28	88	25	54	19	100,5				74,52	4,6	43,
4	16,2	9,34	11,19	78	23	48	20	97,				55,89	3,45	37,26
5	18,	10,38	13,22	66	24	48	18	97,	112	15	98,66	44,7	2,48	29,8
6	19,84	11,44	14,6	66	24	48	20	96,2	112	17	96,2	37,26	1,9	24,84
7	21,43	12,36	15,74	66	25	44	19	96,2	104	17	96,2	31,9	1,48	21,26
8	22,8	13,15	16,75	66	25	44	20	97,2	96	16	100,	27,94	1.22	18,6
9	24,3	14,02	17,86	66	26	42	19	100,2	96	17	100,8	24,84	1,02	16,56
10	25,54	14,73	18,78	60	25	44	20	99,	96	18	100,	22,89	,9	15,26
11	26,73	15,42	19,7	60	26	44	20	100,	96	19	99,5	20,32	,76	13,54
12	28,	16,16	20,5	60	27	44	20	100,	96	20	98,4	18,63	,66	12,42
13	29,16	16,82	21,42	60	27	42	20	99,8	96	21	102,6	16,27	,56	10,8
14	30,2	17,42	22,19	60	28	42	20	99,	88	20	97,63	15,94	,53	10,6
15	31,34	18,08	23,03	60	29	42	20	99,	88	21	96,5	14,9	,47	9,93
16	32,4	18,69	23,8						88	21	99,7	13,97	,43	9,31
17	33,32	19,22	24,48						84	21	97,9	13,14	,39	8,76
18	34,34	19,81	25,23						80	21	96,1	12,42	,36	8,28
19	35,18	20,29	25,82						80	21	98,3	11,76	,33	7.84
20	36,2	20,88	26,6						78	21	98,3	11,17	,3	7,4
21	37,11	21,41	27,26						78	22	97,	10,64	,29	7,1
22	37,98	21,86	27,84						78	22	98.6	10,16	,26	6,77
23	38,79	22,38	28,5						72	21	97,7	9,72	.25	6,48
24	39,69	22,9	29,17						66	20	96,2	9,32	,23	6.21
25	40,5	23,36	29,75						60	18	99,	8,94	,22	5,96
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Note, that five feet fall is the least that a single gear can be built on, to keep the cog-wheel clear of the water, and give the stone sufficient motion.

Although double gear is calculated to fifteen feet fall, yet I do not recommend them above ten feet, unless for some particular convenience, such as two pair of stones to one wheel, &c. &c. The number of cogs in the wheels are even, and chosen to suit eight, six, or four arms, so as not to pass through any of them, this being the common practice. But when the motion cannot be obtained without a trundle that will cause the same cogs and rounds to meet too often, such as 16 into 96, which will meet every revolution of the cog-wheel, or 18 into 96, which will meet every third revolution—I advise rather to put in one more or less, as may best suit the motion, which will cause them to change oftener. See art. 82.

Note, that the friction at the aperture of the gate will greatly diminish both the velocity and power of the water in this application, where the head is great, if the gate be made of the usual form, wide and shallow. Where the head is great, the friction will be great. See art. 55. Therefore the wheel must be narrow, and the aperture of the gate of a square form, to evade the friction and loss that may be under a wide wheel, if it does not run close to the sheeting.

Use of the Table.

Having levelled your mill-seat carefully, and finding such fall and quantity of water as determines you to make choice of an undershot wheel; for instance, suppose 6 feet fall, and about 45 cubic feet of water per second, which you find as directed in art. 53; cast off about 1 foot for fall in the tail-race, below the bottom of the wheel, if subject to back-water, leaves you 5 feet head; look for five feet head in the first column of the table, and against it are all the calculations for a 15 feet water-wheel and 5 feet stones; in the thirteenth column you have 44,7 cubic feet of water; which shews you have enough for a five feet pair of stones; and the velocity

of the water will be 18 feet per second, the velocity of the wheel 10,38 feet per second, and it will revolve 13,22 times per minute. And if you choose double gear, then 66 cogs in the master cog-wheel, 24 rounds in the wallower, 48 cogs in the counter cog-wheel, and 18 rounds in the trundle, will give the stone 97 revolutions in a minute; if single gear, 112 cogs and 15 rounds give 98,66 revolutions in a minute; it will require 44,7 cubic feet of water per second; the size of the gate must be 2,48 feet, which will be about 4 feet wide and ,62 feet deep, about 7¼ inches deep; the size of the canal must be 29,8 feet; that is, about 3 feet deep, and 9,93 or nearly 10 feet wide. If you choose single gear, you must make your water-wheel much less, say 7½ feet, the half of 15 feet, then the cog-wheel must have half the number of cogs, the trundle-head the same, the spindle will be longer, husk lower, and the mill full as good; but in this case, it will not do, because a cog-wheel of 66 cogs would reach the water; but where the head is 10 or 12 feet, it will do very well.

If you choose stones, or water-wheels, of other sizes, it will be easy, by the rules by which the table is calculated, to proportion the whole to suit, seeing you have the velocity of the periphery of a wheel of any size.*

* One advantage large wheels have over small ones is, they cast off the back-water much better. The buckets of the low wheel will lift the water much more than those of the high wheel; because the nearer the water rises to the centre of the wheel, the nearer the buckets approach the horizontal or lifting position.

To make a wheel cast off back-water, fix the sheeting below the wheel, with joints and hinges, so that the end down stream can be raised to shoot the water as it leaves the wheel on the surface of the back-water, to roll it from the wheel, and it will drive off the back-water much better. So says Adrian Dawes, mill-wright, Jersey.

Plate IV. Fig. 28, is an undershot wheel. Some prefer to slant the fore-bay under the wheel, as in the figure, that the gate may be drawn near the floats; because (say they) the water acts with more power near the gate, than at a distance; which appears to be the case, when we consider, that the nearer we approach the gate, the nearer the column of water approaches, to be what is called a perfect definite quantity. See art. 59.

Others again say, that it acquires equal power in descending the shute (it will certainly acquire equal velocity abating only for the friction of the shute and air.) When the shute has a considerable descent, the greater the distance from the gate, the greater the velocity and power of the water; but where the descent of the shute is not sufficient to overcome the friction of the air, &c. then the nearer the gate, the greater the velocity and power

Observations on the Table.

1. It is calculated for an undershot wheel constructed, and the water shot on, as in plate IV, fig. 28. The head is counted from the point of impact I, and the motion of the wheel at a maximum, about ,58 of the velocity of the water; but when there is plenty of water, and great head, the wheel will run best at about ,66 or two-thirds of the velocity of the water; therefore the stones will incline to run faster than in the table, in the ratio of 58 to 66, nearly; for which reason, I have set the motion of 5 feet stones under 100 revolutions in a minute, which is slower than common practice; they will incline to run between 96 and 110 revolutions.

2. I have taken half of the whole head above the point of impact, for the virtual or effective head, by art. 53; which appears to me will be too little in very low heads, and perhaps too much in high ones. As the principle of non-elasticity does not appear to me to operate against the power so much in low as in high heads, therefore if the head be only 1 foot, it may not require 223,5 cubic feet of water per second, and if 20 feet, may require more than 11,17, cubic feet of water per second, as in the table. See art. 8.

ART. 71.

OF TUB MILLS.

A tub mill has a horizontal water-wheel, that is acted on by the percussion of the water altogether; the shaft

of the water; which argues in favour of drawing the gate near the floats. Yet, where the fall is great, or water plenty, and the expense of a deep penstock considerable, the small difference of power is not worth the expense of obtaining. In these cases, it is best to have a shallow penstock, and a long shute to convey the water down to the wheel, drawing the gate at the top of the shute: which is frequently done to save expense, in building saw-mills, with flutter-wheels, which are small undershot wheels, fixed on the crank, so small as to obtain a sufficient number of strokes of the saw in a minute, say about 120. This wheel is to be calculated of such a size as to suit the velocity of the water at the point of impact, so as to make that number of revolutions in a minutes.

For the method of shooting the water on an undershot wheel, where the fall is great, see Thomas Ellicott's plan, part 5, plate I, fig. 6.

is vertical, carrying the stone on the top of it, and serves in place of a spindle; the lower end of this shaft is set in a step fixed in a bridge-tree, by which the stone is raised and lowered, as by the bridge-tree of other mills; the water is shot on the upper side of the wheel, in a tangent direction with its circumference. See fig. 29, plate IV, which is a top view of the tub-wheel, and fig. 30 is a side view of it, with the stone on the top of the shaft, bridge-tree, &c. The wheel runs in a hoop, like a mill-stone hoop, projecting so far above the wheel as to prevent the water from shooting over the wheel, and whirls it about until it strikes the buckets, because the water is shot on in a deep narrow column, 9 inches wide and 18 inches deep, to drive a 5 feet stone, with 8 feet head—so that all this column cannot enter the buckets until part has passed half way round the wheel, so that there are always nearly half the buckets struck at once; the buckets are set obliquely, so that the water may strike them at right angles. See Plate IV. fig. 30. As soon as it strikes it escapes under the wheel in every direction, as in fig. 29.*

* Note, That in plate IV. fig. 30, I have allowed the gate to be drawn inside of the penstock, and not in the shute near the wheel, as is the common practice; because the water will leak out much along side of the gate, if drawn in the shute. But here we must consider, that the gate must always be full drawn and the quantity of water regulated by a regulator in the shute near the wheel; so that the shute will be perfectly full, and pressed with the whole weight of the head, else a great part of the power may be lost.

To shew this more plain, suppose the long shute A, from the high head (shewn by dotted lines) of the undershot mill, fig. 28, be made tight by being covered at top, then, if we draw the gate A, but not fully, if the shute at bottom be large enough to vent all the water that issues through the gate when the shute is full to A, then it cannot fill higher than A; therefore all that part of the head above A is lost, it being of no other service than to supply the shute, and keep it full to A, and the head from A to the wheel is all that acts on the wheel.

Again, when we shut the gate, the shute cannot run empty, because it would leave a vacuum in the head of the shute at A; therefore the pressure of the atmosphere resists the water from running out of the shute, and whatever head of water is in the shute, when the gate is shut, will balance its weight of the pressure of the atmosphere, and prevent it from acting on the lower side of the gate, which will cause it to be very hard to draw. For, suppose 11 feet head of water to be in the shute when the gate was shut, its pressure is equal to about 5 lb. per square inch; then, if the gate be 48 by 6 inches, which is equal to 288 inches, this multiplied by 5, is equal to 1440 lb. the additional pressure on the gate.

Again, if the gate be full drawn, and the shute be not much larger at the upper than lower end, all these evils will take place to cause the loss

The disadvantages of these wheels are,

1. The water does not act to advantage on them, we being obliged to make them so small to obtain velocity to the stone (in most cases) that the buckets take up a third part of their diameter.

2. The water acts with less power than on undershot wheels, as it is less confined at the time of striking the wheel, and its non-elastic principle takes place more fully. See art. 8.

3. It is with difficulty we can put a sufficient quantity of water to act on them to drive them with sufficient power, if the head be low; therefore I advise to strike the water on in two places, as in Plate IV. fig. 29; then the apertures need only be about 6 by 13 inches each, instead of 9 by 18, and will act to more advantage; and then, in this case, nearly all the buckets will be acted on at once.

Their advantages are,

Their exceeding simplicity and cheapness, having no cogs nor rounds to be kept in repair; their wearing parts are few, and have but little friction; the step-gudgeon runs under water, therefore, if well fixed, will not get out of order in a long time; and they will move with sufficient velocity and power with 9 or 10 feet total fall, and plenty of water; and, if they be well fixed, they will not require much more water than undershot wheels; therefore they are vastly preferable in all seats with plenty of water, and above 8 feet fall.

In order that the reader may fully understand how the following table is calculated, let him consider,

1. That as the tub-wheel moves altogether by percussion, the water flying clear of the wheel the instant it

of power. To remedy all this, put the gate H at the bottom of the shute to regulate the quantity of water by, and make a valve at A to shut on the inside of the shute, like the valve of a pair of bellows, which will shut when the gate A is drawn, and open when the gate shuts, to let air into the shute; this plan will do better than long open shutes, for saw-mills with flutter-wheels or tub-mills, as by it we evade the friction of the shute and resistance of the air.

The reader will with difficulty understand what is here said, unless he be acquainted with the theory of the pressure of the atmosphere, vacuums, &c. See these subjects, touched on in art. 56.

strikes, and it being better, by art. 70, for such wheels to move faster instead of slower than the maximum velocity; therefore, instead of ,577, we will allow them to move ,66 velocity of the water; then multiplying the velocity of the water by ,66, gives the velocity of the wheel, at the centre of the buckets; which is the 3d column in the table.

2. And the velocity of the wheel per second, multiplied by 60, and divided by the number of revolutions the stone is to make in a minute, gives the circumference of the wheel at the centre of the buckets; which circumference, multiplied by 7, and divided by 22, gives the diameter from the centre of the buckets, to produce the number of revolutions required; which are the 4th, 5th, 6th, and 7th columns.

3. The cubochs of power required, by art. 63, to drive the stone, divided by half the head, gives the cubic feet of water required to produce said power; which are the 8th and 10th columns.

4. The cubic feet of water, divided by the velocity, will give the sum of the apertures of the gates; which are the 9th and 11th columns.

5. The cubic feet of water, divided by 1,5 feet, the velocity of the water in the canal, gives the area of a section of the canal; which are the 12th and 13th columns.

6. For the quantity of water, aperture of gate, and size of canal, for 5 feet stones, see table for undershot mills, in art. 70.

THE MILL-WRIGHT'S TABLE

FOR

TUB MILLS.

Head of water above the point of impact or top of the wheel.	Velocity of the water per second.	Velocity of the wheel, counted at the centre of the buckets, and being ,66 velocity of the water.	Diameter of the wheel, to the centre of the buckets, for a stone 4 feet diameter, 122 revolutions in a minute.	Ditto for a 5 feet stone, to revolve 98 times in a minute.	Ditto for a 6 feet stone, to revolve 81 times in a minute.	Ditto for a 7 feet stone, to revolve 70 times in a minute.	Cubic feet of water per second, required to drive the 4 feet stones.	Sum of the areas of the apertures of the gate for a 4 feet stone.	Cubic feet of water required, per second, for a 6 feet stone.	Sum of the areas of the apertures for a 6 feet stone.	Area of a section of the canal sufficient to bring the water to 4 feet stones, with a velocity of 1,5 feet per second.	Ditto for 6 feet stones.
ft	feet.	feet.	feet.	feet.	feet.	feet.	cub. ft.	su ft.	cub. ft.	su. ft.	sup. ft.	sup. ft.
8	22.8	15,04	2,17	2,73	3,3	3,9	17,34	,76	40.9	1,79	11,56	27,3
9	24,3	16,03	2,5	3,12	3,68	4,37	15,41	,64	36,35	1,5	10,3	24,23
10	25,54	16,85	2,63	3,28	3,97	4,59	13,87	,54	32,72	1,28	9 25	21,7
11	26,73	17,64	2.75	3.44	4,15	4,8	12,61	,47	29,74	1,11	8,4	19,83
12	28,	18,48	2,9	3,6	4,34	4,9	11,56	,41	27,26	.97	7,7	18.17
13	29,16	19,24	3,01	3,74	4,53	5,24	10,67	,36	25,17	.86	7,1	16.8
14	30,2	19,93	3,12	3,9	4,7	5,43	9,9	,33	23,36	,77	6,6	15,56
15	31,34	20,68	3,24	4,03	4,87	5,67	9,24	,29	21,93	,7	6,16	14,62
16	32,4	21,38	3,34	4,12	5,01	5,83	8,67	,27	20.45	,6	5,71	13,6
17	33,32	21,99	3,43	4,25	5,18	5,95	8,16	,24	19,24	,57	5,44	12,15
18	34,34	22,66	3,54	4 41	5,32	6,18	7,7	,22	18,18	,52	5,13	12,12
19	35,18	23,21	3,63	4.52	5,47	6,33	7,3	,2	17,	,48	4,9	11,33
20	36,2	23,89	3,71	4,62	5.49	6,47	6,93	,19	16,36	,45	4,62	10.9
1	2	3	4	5	6	7	8	9	10	11	12	13

Use of the Table for Tub Mills.

Having levelled your seat, and finding that you have above 8 feet fall, and plenty of water, and wish to build a mill on the simplest, cheapest, and best construction to suit your seat, you will, of course, make choice of a tub mill.

Cast off 1 foot for fall in the tail-race below the bottom of the wheel, if it be subject to back-water, and 9 inches for the wheel; then suppose you have 9 feet left for head above the wheel; look in the table, against 9 feet head, and you have all the calculations necessary for 4, 5, 6, and 7 feet stones, the quantity of water required to drive them, the sum of the areas of the apertures, and the areas of the canals.

If you choose stones of any other size, you can easily proportion the parts to suit, by the rules by which the table is calculated.

ART. 72.

OF BREAST MILLS.

Breast wheels, which have the water shot on them in a tangent direction, are acted on by the principles of both percussion and gravity; all that part above the point of impact, called head, acts by percussion, and all that part below said point, called fall, acts by gravity.

We are obliged, in this structure of breast mills, to use more head than will act to advantage; because we cannot strike the water on the wheel, in a true tangent direction, higher than I, the point of impact in Plate IV, fig. 31, which is a breast-wheel, with 12 feet perpendicular descent, 6,5 feet of which is above the point I, as head, and 5,5 feet below, as fall. The upper end of the shute, that carries the water down to the wheel, must project some inches above the point of the gate when full drawn, else the water will strike towards the centre of the wheel; and it must not project too high, else the water

in the penstock will not come fast enough into the shute when the head sinks a little. The bottom of the penstock is a little below the top end of the shute, to leave room for stones and gravel to settle, and prevent them from getting into the gate.

We might lay the water on higher, by setting the top of the penstock close to the wheel, and using a sliding gate at bottom, as shewn by the dotted lines; but this is not approved of in practice. See Ellicott's mode, part 5, plate III, fig. 1.

But if the water in the penstock be nearly as high as the wheel, it may be carried over, as by the upper dotted lines, and shot on backwards, making that part next the wheel the shute to guide the water into the wheel, and the gate very narrow or shallow, allowing the water to run over the top of it when drawn; by this method (called Pitchback) the head may be reduced to the same as it is for an overshot wheel; and then the motion of the circumference of the wheel will be equal to the motion of an overshot wheel, whose diameter is equal to the fall below the point of impact, and their power will be equal.

This structure of a wheel, Plate IV. fig. 31, I take to be a good one, for the following reasons, viz.

1. The buckets, or floats, receive the percussion of the water at right angles, which is the best direction possible.

2. It prevents the water from flying towards the centre of the wheel, without re-acting against the bottom of the buckets, and retains it in the wheel, to act by its gravity in its descent, after the stroke.

3. It admits air, and discharges the water freely, without lifting it at bottom; and this is an important advantage, because, if the buckets of a wheel be tight, and the wheel wades a little in back-water, they will lift the water a considerable distance as they empty; the pressure of the atmosphere prevents the water from leaving the buckets freely, and it requires a great force to lift them out of the water with the velocity of the wheel; which may be proved by dipping a common water-bucket into water, and lifting it out, bottom up, with a quick motion, you have to lift not only the water in the

bucket, but it appears to suck a deal more up after it; which is the effect of the pressure of the atmosphere, See art. 56. This shews the necessity of air-holes to let air into the buckets, that the water may have liberty to get out freely.

Its disadvantages are,

1. It loses the water much, if it is not kept close to the sheeting. And,

2. It requires too great a part of the total fall to be used as head, which is a loss of power, one foot fall being equal in power to two feet head, by art. 8.

Plate IV. Fig. 32 is a draught, shewing the position of the shute for striking the water on a wheel in a tangent direction, for all the total perpendicular descents from 6 to 15 feet; the points of impact are numbered inside the fig. with the number of the total fall, that each is for respectively. The top of the shute is only about 15 inches from the wheel, in order to set the point of impact as high as possible, allowing 3 feet above the upper end of the shute to the top of the water in the penstock, which is little enough, when the head is often to be run down any considerable distance; but where the stream is steady, being always nearly the same height in the penstock, 2 feet would be sufficient, especially in the greatest total falls; where the quantity is less, raising the shute 1 foot would raise the point of impact nearly the same, and increase the power, because 1 foot fall is equal in power to 2 feet head, by art. 61.

On these principles, to suit the applications of water, as represented by fig. 32, I have calculated the following table for breast mills. And, in order that the reader may fully understand the principles on which it is calculated, let him consider as follows:

1. That all the water above the point of impact, called head, acts wholly by percussion, and all below said point, called fall, acts wholy by gravity, (see art. 60,) and form the 2d and 3d columns.

2. That half the head, added to the whole fall, constitutes the virtual or effective descent, by art. 61; which is the 4th column.

3. That if the water was permitted to descend freely down the circular sheeting, after it passes the point of impact, its velocity would be accelerated, by art. 60, to be, at the lowest point, equal to the velocity of water spouting from under a head equal to the whole descent; therefore the maximum velocity of this wheel will be a compound of the velocity to suit the head and the acceleration after it passes the point of impact. Therefore, to find the velocity of this wheel, I first multiply the velocity of the head, in column 5, by ,577, (as for undershot mills,) which gives the velocity suitable to the head; I then, (by the rule for determining the velocity of overshots,) say, as the velocity of water descending 21 feet, equal to 37,11 feet per second, is to the velocity of the wheel 10 feet per second, so is the acceleration of velocity, after it passes the point of impact, to the accelerated velocity of the wheel; and these two velocities added, gives the velocity of the wheel; which is the 6th column.

4. The velocity of the wheel per second, multiplied by 60, and divided by the circumference of the wheel, gives the revolutions per minute; 7th column.

5. The number of cogs in the cog-wheel, multiplied by the number of revolutions of the wheel per minute, and divided by the rounds in the trundle-head, will give the number of revolutions of the stone per minute; and if we divide by the number of revolutions the stone is to have, it gives the rounds in the trundle, and, when fractions arise, take the nearest whole number; columns 8, 9, and 10.

6. The cubochs of power required to turn the stone, by art. 63, divided by the virtual descent, gives the cubic feet of water required per second; column 11.

7. The cubic feet, divided by the velocity of water allowed in the canal, suppose 1,5 feet per second, gives the area of a section of the canal; column 12.

8. If the mill is to be double geared, take the revolutions of the wheel from column 7 of this table, and look in column 4 of the undershot table, art. 70, for the number of revolutions nearest to it, and against that number you have the gears that will give a 5 feet stone the right motion.

THE MILL-WRIGHT'S TABLE

FOR

BREAST MILLS,

Calculated for a Water-wheel fifteen Feet, and Stones five Feet, diameter; the Water being shot on in a tangent direction to the circumference of the Wheel.

Total perpendicular descent or fall of the water from the top of the water in the penstock, to ditto in tail race.	Head above the point of impact.	Fall below the point of impact.	Virtual or effective descent, being half the head added to the fall.	Velocity of the water per second at the point of impact.	Velocity of the circumference of the wheel per second.	Number of revolutions of a wheel fifteen feet diameter, per minute.	Cogs in the cog-wheel, for single gear.	Rounds in the trundle head.	Revolutions of the stone per minute.	Cubic feet of water required per second.	Area of a section of the canal, allowing the velocity of the water in it to be 1,5 feet per second.
feet.	feet	feet.	feet.	feet.	feet.	No.	No.	N.	No.	cub. ft.	su. ft.
6	4,5	1,5	3,75	17,13	10,61	13,5	112	15	100,8	29,8	19,25
7	5,	2,	4,5	18,	11,3	14,4	112	16	100,8	24.83	16,55
8	5,5	2.5	5,25	18,99	12,07	15,3	104	16	99,4	21,29	14,19
9	5.9	3,1	6,05	19,48	12,53	16,	104	16	102,7	18,45	12,3
10	6,2	3,8	6,9	20,16	13,07	16,6	96	16	99,6	16,2	10,8
11	6.5	4,5	7,75	20,64	13,53	17,	96	16	102,	14,42	9,61
12	6,8	5,3	8,7	21,11	14,03	17,81	96	17	100,5	12,73	8,49
13	6,8	6,2	9.6	21,11	14,35	18,28	96	18	97,5	11,63	7,75
14	6,9	7,1	10,55	21,3	14,41	18.35	96	18	97,8	10,59	7,06
15	7,	8,	11,5	21,13	14.76	18,56	96	18	98,4	9,72	6,48
1	2	3	4	5	6	7	8	9	10	11	12

Use of the Table for Breast Mills.

Having a seat with above 6 feet fall, but not enough for an overshot mill, and the water being scarce, so that you wish to make the best use of it, leads you to the choice of a breast mill.

Cast off about 1 foot for fall in the tail race below the bottom of the wheel, if much subject to back-water; and suppose you have then 9 feet total descent; look for it in the first column of the table, and against it you have it divided into 5,9 feet head above, and 3,1 feet fall below the point of impact, which is the highest point that the water can be fairly struck on the wheel, leaving the head 3 feet deep above the shute; which is equal to 6,5 feet virtual or effective descent; the velocity of the water striking the wheel 18,99 feet, velocity of the wheel 12,07 feet per second, will revolve 16 times in a minute; and, if single geared, 104 cogs, and 16 rounds, gives the stone 99,4 revolutions in a minute, requires 21,29 cubic feet of water per second; the area of a section of the canal must be 14,19 feet, about 3 feet deep, and 5 feet wide. If the stones be of any other size, it is easy to proportion the gears to give them any number of revolutions required.

If you wish to proportion the size of the stones to the power of your seat, multiply the cubic feet of water your stream affords per second, by the virtual descent in column 4, and that product is the power in cubochs; then look in the table, in art. 63, for the size of the stone that nearest suits that power.

For instance, suppose your stream affords 14 cubic feet of water per second, then 14 multiplied by 6,05 feet virtual descent, produces 84,7 cubochs of power; which, in the table in art. 63, comes nearest to 4,5 feet for the diameter of the stones; but, by the rules laid down in art. 63, the size may be found more exactly.

Note, 6 cubochs of power are required to every superficial foot of the stones.

ART. 73.

OF OVERSHOT MILLS.

Fig. 33, plate IV, is an overshot wheel; the water is laid on at the top, so that the upper part of the column will be in a true tangent direction with the circumference of the wheel, but so that all the water may strike within the circle of the wheel.

The gate is drawn about 30 inches behind the perpendicular line from the centre of the wheel, and the point of the shute ends at said perpendicular, with a direction a little downwards, which gives the water a little velocity downwards to follow the wheel; for if it be directed horizontally, the head will give it no velocity downwards and if the head be great, the parabolic curve, which the spouting water forms, will extend beyond the outside of the circle of the wheel, and it will incline to fly over. See art. 44 and 60.

The head above the wheel acts by percussion, as on an undershot wheel, and we have shewn, art. 43, that the head should be such as to give the water velocity 3 for 2 of the wheel. After the water strikes the wheel it acts by gravity; therefore, to calculate the power, we must take half the head and add it to the fall, for the virtual descent, as in breast mills.

The velocity of overshot wheels is as the square roots of their diameters. See art. 43.

On these principles, I have calculated the following table for overshot wheels; and, in order that the reader may understand it fully, let him consider well the following premises:

1. That the velocity of the water spouting on the wheel must be one and a half the velocity of the wheel, by art. 43: then, to find the head that will give said velocity, say, as the square of 16,2 feet per second, is to 4 feet, the head that gives that velocity, so is the square of the velocity required, to the head that will give that velocity: but to this head, so found, we must add a little by conjecture, to overcome the friction of the aperture. See art. 55.

In this table, I have added to the heads of wheels from 9 to 12 feet diameter ,1 of a foot, and from 12 to 20 I have added 1 tenth more, for every foot increase of diameter, and from 20 to 30 feet I have added ,05 more to every foot diameter's increase; which gives a 30 feet wheel 1,5 feet additional head, while a nine feet wheel has only, 1 tenth of a foot, to overcome the friction. The reason of this great difference will appear when we consider that the friction increases as the aperture decreases, and as the velocity increases: but this much depends on the form of the gate, for if that be nearly square, there will be but little friction, but if very oblong, say 24 inches by half an inch, then it will be very great.

The heads, thus found, compose the 3d column.

2. The head, added to the diameter of the wheel, makes the total descent, as is column 1.

3. The velocity of the wheel per second, taken from the table in art. 43, and multiplied by 60, and divided by the circumference of the wheel, quotes the number of revolutions of the wheel per minute, and is column 4.

4. The number of revolutions of the wheel per minute, multiplied by the number of cogs in all the driving wheels successively, and that product divided by the product of all the leading wheels, quotes the number of revolutions of the stone per minute, and is column 9, double gear, for 5 feet stones; and column 12, single gear, for 6 feet stones.

5. The cubochs of power required to drive the stone, by table in art. 63, divided by the virtual or effective descent, which is half the head added to the (fall or) diameter of the wheel, quotes the cubic feet of water required per second to drive the stone, and is column 13.

6. The cubic feet required, divided by the velocity you intend the water to have in the canal, quotes the area of a section of the canal. The width multiplied by the depth, must always produce this area. See art. 64.

7. The number of cogs in the wheel, multiplied by the quarter inches in the pitch, produces the circumference of the pitch circle; which, multiplied by 7, and

divided by 22, quotes the diameter in quarter inches; which, reduced to feet and parts, is column 15. The reader may here at once observe how near the cog-wheel, in the single gear, will be to the water; that is, how near it is, in size, equal to the water-wheel.

Use of the Table.

Having with care levelled the seat on which you mean to build, and found, that after deducting 1 foot for fall below the wheel, and a sufficiency for the sinking of the head race, according to its length and size, and having a total descent remaining sufficient for an overshot wheel, suppose 17 feet; then look in column 1 of the table, for the descent nearest to it, we find 16,74 feet, and against it a wheel 14 feet diameter; head above the wheel 2,7 feet; revolutions of the wheel per minute 11,17; (and double gears, to give a 5 feet stone 98,7 revolutions per minute; also, single gears, to give a 6 feet stone 76,6 revolutions per minute;) the cubic feet of water required for a 5 feet stone 7,2 feet per second, and the area of a section of the canal 5 feet, about 2 feet deep, and 2,5 feet wide.

If you choose to proportion the size of the stones exactly to suit the power of the seat, do it as directed in art. 63. All the rest can be proportioned by the rules by which the table is calculated.

THE MILL-WRIGHT'S TABLE

FOR

OVERSHOT MILLS,

CALCULATED FOR FIVE FEET STONES, DOUBLE GEAR, AND SIX FEET STONES, SINGLE GEAR.

				Double gear, 5 feet stones.					Single gear, 6 ft. stones.						
Total descent of the water, which is in this table made to suit the diameter of the wheel and head above it.	Diameter of the wheel.	Head above the wheel, allowing for the friction of the aperture, so as to give the water velocity 3 for 2 of the wheel.	Number of revolutions of the wheel per minute.	No. of cogs in master cog-wheel.	Rounds in the wallower.	Cogs in the counter cog-wheel.	Rounds in the trundle.	Revolutions of the stone per minute.	Cogs in the cog-wheel.	Rounds in the trundle.	Revolutions of the stone per minute.	Cubic feet of water required per second, for five feet stones.	Area of a section of the canal, allowing the velocity of the water in it to be 1 foot per second.	Diameter of the pitch circle of the great cog-wheels for single gear, pitch 4 1-4 inches.	
feet.	ft.	feet.										cu.ft.	sup. ft.	feet.	inches.
10,51	9	1,51	14,3	54	21	44	16	102,9	60	11	78,	11,46	11,46	6:9 0-4	12-22
11,74	10	1,74	13,	54	21	48	18	98,	60	10	78,	10,3	10,3		
12,94	11	1,94	12,6	60	21	48	18	96,	66	11	75,6	9,34	9,34	7:5 1-4	
14,2	12	2,2	12,	66	23	48	17	97,	66	10	79,2	8,53	8,53		
15,47	13	2,47	11,54	66	21	48	17	99,3	84	12	80,7	7,92	7,92	9:5 1-2	
16,74	14	2,74	11,17	72	23	48	17	98,7	96	14	76,6	7,2	7,2	10:9 3-4	6-22
17,99	15	2,99	10,78	78	23	48	18	98,3	96	13	81,9	6,77	6,77		
19,28	16	3,28	10,4	78	23	48	17	99,5	120	16	76,	6,4	6,4	13:6 1-4	2-22
20,5	17	3,5	10,1	78	21	48	18	96,6	120	15	80,8	6,	6,		
21,8	18	3,8	9,8	84	24	48	17	97,	128	16	78,4	5,56	5,56	14:5 0-4	8-22
23,03	19	4,03	9,54	84	23	48	17	98,3	128	15	81,4	5,32	5,32		
24,34	20	4,34	9,3	88	23	48	17	100,	128	15	79,3	5,04	5,04		
25,54	21	4,54	9,1	88	23	48	17	98,3	128	15	77,6	4,81	4,81		
26,86	22	4,86	8,9	96	24	48	17	100.5	128	14	81,4	4,57	4,57		
27,99	23	4,99	8,7	96	25	54	18	100,2				4,34	4,34		
29,27	24	5,27	8,5	96	25	54	17	103,				4,19	4,19		
30,45	25	5,45	8,3	96	25	54	17	101,				4,	4,		
31,57	26	5,57	8,19	96	25	54	17	99,6				3,82	3,82		
32,77	27	5,77	8,03	104	25	54	18	100,2				3,7	3,7		
33,96	28	5,96	7,93	104	25	54	18	99,				3,6	3,6		
35,15	29	6,15	7,75	112	26	54	18	100,1				3,4	3,4		
36,4	30	6,4	7,63	112	26	54	18	98,6				3,36	3,36		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

Observations on the Table.

1. It appears, that single gear does not much suit this construction; because, where the water-wheels are low, their motion is so slow that the cog-wheels, (if made large enough to give sufficient motion to the stone, without having the trundle too small, see art. 23,) will touch the water: And again, when the water-wheels are high, above 20 feet, the cog-wheels require to be so high, in order to give motion to the stone without having the trundle too small, that they become unwieldy, and the husk too high, spindle short, &c. so as to be inconvenient. Therefore, single gear seems to suit overshots only where the diameter of the water-wheel is between 12 and 18 feet; and even with them the water-wheel will have to run rather too fast, or the trundle be rather too small, and the stones should be 6 feet diameter at least.

2. I have, in the preceding tables, allowed the water to pass along the canal with 1,5 feet per second velocity; but have since concluded that 1 foot per second is nearer the proper motion; that is, about 20 yards per minute; then the cubic feet required per second, will be the area of a section of the canal, as in column 14 of this table.

3. Although I have calculated this table for the velocities of the wheels to vary as the square roots of their diameters, which makes a 30 feet wheel move 11,99 feet per second, and a twelve feet wheel to move 7,57 feet per second; yet they will do to have equal velocity, and head, which is the common practice among mill-wrights. But, for the reasons I have mentioned in art. 43, I prefer giving them the velocity and head assigned in the table, in order to obtain steady motion.

4. Many have been deceived, by observing the exceeding slow and steady motion of some very high overshot wheels working forge or furnace bellows, concluding therefrom, that they will work equally steady with a very slow as with any quicker motion, not considering, perhaps, that it is the principle of the bellows that regulates the motion of the wheel, which is different from any

other resistance, for it soon becomes perfectly equable; therefore the motion will be uniform, which is not the case with any kind of mills.

5. Many are of opinion, that water is not well applied by an overshot wheel; because, say they, those buckets near above or below the centre, act on too short a lever. In endeavouring to correct this error, I have divided the fall of the overshot wheel, fig. 33, plate IV, into feet, by dotted lines. Now, by art. 53 and 54, every cubic foot of water on the wheel produces an equal quantity of power in descending each foot perpendicular, called a cuboch of power; because, where the lever is shortest, there is the greatest quantity of water within the foot perpendicular; or, in other words, each cubic foot of water is a much longer time, and passes a greater distance, in descending a foot perpendicular, than where it is longest; which exactly compensates for the deficiency in the length of lever. And, considering that the upper and lower parts of the wheel do not run away from the gravity of the water, so much as the breast of the wheel, we must conclude, that the upper and lower feet of perpendicular descent (in theory) actually produce more power than the middle two feet; but (in practice) the lower foot is entirely lost, by the spilling of the water out of the buckets. See this demonstrated, art. 54.*

Of Mills moved by Re-action.

We have now treated of the four different kinds of mills that are in general use. There are others, the invention or improvements of the late ingenious James Rumsey, which move by the re-action of the water. One

* The Messrs. Ellicotts have constructed overshot wheels at their mills near Baltimore, so that they retain the water the whole of its descent, delivering it under the centre of the wheel. This is done by half soaling the wheel outside of the rim, and to prevent the water from splashing over the sides as it comes on the wheel, they extend the rim outside of the buckets by nailing round it two pieces one and a half inch thick, on each rim, increasing the diameter three inches; these also help to hold in the buckets and soaling firmly. Two advantages are expected from this construction; first, retaining the water the whole of the descent; secondly, the wheel will run more steadily, as it cannot fly off as rapidly when the resistance is taken off, as it would have left the water on the rising side.

of these is said to do well where there is much back-water; it being small, and of a true circular form, the back-water does not resist it much. I shall say but little of these, supposing the proprietors mean to treat of them; but may say, that there appears to me but two principles by which water can be applied to move mill-wheels, viz. Percussion and Gravity.

For the different effects of equal quantities of water, with equal perpendicular descents, applied by these different principles, see art. 8 and 68.

Water may be applied, by percussion, two ways, viz. by action (which is when it strikes the floats of a wheel) and by re-action, which is when it issues from within the wheel, and, by its re-action, moves it round; and these two are equal, by 3d general law of motion, art. 7.

For the effects of centrifugal force, and the inertia of the water, on this application of re-action, see axioms I, and II, art. 1; and art. 13. The principle of inertia will operate in proportion to the quantity of water used; therefore this application will suit high heads better than low ones.

Water may be applied, by gravity, two ways, viz. either by spouting it high on the wheel, into tight buckets, as on common overshots, or by causing the whole head of water to press on the floats, at the lower side of the wheel, which is so constructed that the water cannot escape, but as the wheel moves, and at the same time keeping clear of the paradoxical principle mentioned in arts. 48 and 59; which cannot be done unless the floats are made to move on pivots, so as to fold in on one side of the wheel, and open out, to receive the weight of the water, on the other. And these two applications are equal in theory, as will appear plain by art. 54, plate III. fig. 20; yet they may differ greatly in practice.*

* In the year 1786, I invented and made a model of a wheel of this structure, intending thereby to apply steam to propel land-carriages, and exhibited a drawing thereof to the legislature of Maryland, and obtained a patent (for my improvements in mills, and also) for applying steam to land-carriages, in that state; but could not attend to put it in practice. Since which time, the late ingenious James Rumsey has applied this wheel to water-mills, which I did not intend to do. This may properly be called the Valve Wheel.

CHAPTER II.

ART. 74.

RULES AND CALCULATIONS.

THE fundamental principle, on which is founded all rules for calculating the motion of wheels, produced by a combination of wheels, and for calculating the number of cogs to be put in wheels, to produce any motion that is required, see in art. 20; which is as follows:

If the revolutions that the first moving wheel makes in a minute be multiplied by the number of cogs in all the driving wheels successively, and the product noted; and the revolutions of the last leading wheel be multiplied by the number of cogs in all the leading wheels successively, and the product noted; these products will be equal in all possible cases. Hence we deduce the following simple rules:

1st. For finding the motion of the mill-stone; the revolutions of the water-wheel, and cogs in the wheels, being given,

RULE.

Multiply the revolutions of the water-wheel per minute, by the number of cogs in all the driving wheels successively, and note the product; and multiply the number of cogs or rounds in all the leading wheels successively, and note the product; then divide the first product by the last, and the quotient is the number of revolutions of the stone per minute.

EXAMPLE.

Given, the revolutions of the water-wheel per minute, - - - - - - -		10,4
No. of cogs in the master cog-wheel	78	Drivers.
No. of do. in the counter cog-wheel	48	

No. of rounds in the wallower	-	23	Leaders.
No. of do. in the trundle	-	17	

Then 10,4, the revolutions of the water-wheel, multiplied by 78, the cogs in the master wheel, and 48, the cogs in the counter wheel, is equal to 38937,6; and 23 rounds in the wallower, multiplied by 17 rounds in the trundle, is equal to 391, by which we divide 38937,6, and it quotes 99,5, the revolutions of the stone per minute; which are the calculations for a 16 feet wheel, in the overshot table.

2d. For finding the number of cogs to be put in the wheels, to produce any number of revolutions required to the mill-stone, or any wheel,

RULE.

Take any suitable number of cogs for all the wheels, except one; then multiply the revolutions of the first mover per minute, by all the drivers, except the one wanting (if it be a driver) and the revolutions of the wheel required, by all the leaders, and divide the greatest product by the least, and it will quote the number of cogs required in the wheel to produce the desired revolutions.

Note, if any of the wheels be for straps, take their diameter in inches and parts, and multiply and divide with them, as with the cogs.

EXAMPLE.

Given, the revolutions of the water-wheel	-		10,4
And we choose cogs in master wheel		78	Drivers.
Ditto in the counter wheel	-	48	
And rounds in the wallower	-	23	

The number of the trundle is required, to give the stone 99 revolutions.

Then 10,4 multiplied by 78, and 48, is equal to 38937,6; and 99, multiplied by 23, is equal to 2277, by which divide 38937,6, and it quotes 16,66; instead of which, I take the nearest whole number, 17, for the rounds in the trundle, and find, by rule 1st, that it produces 99,5 revolutions, as required.

For the exercise of the learner, I have constructed fig. 7, plate XI; which I call a circle of motion, and which serves to prove the fundamental principle on which the rules are founded; the first shaft being also the last of the circle.

A	is a cog-wheel of	20	cogs, and is a	driver.
B	do.	24	-	leader.
C	do.	24	-	driver.
D	do.	30	-	leader.
E	do.	25	-	driver.
F	do.	30	-	leader.
G	do.	36	-	driver.
H	do.	20	-	leader.

But if we trace the circle the backward way, the leaders become drivers.

I	is a strap-wheel	$14\frac{1}{2}$	inches diameter,	driver.
K	do.	30	do. -	leader.
L	cog-wheel	12	cogs, -	driver.
M	do.	29	do. -	leader.

MOTION OF THE SHAFTS.

The upright shaft, and first driver, AH 36 revs. in a min.
BC 30 do.
DE 24 do.
FG 20 do.
HA 36 do.
M 4 do. which is the shaft of a hopperboy.

If this circle be not so formed, as to give the first and last shafts (which are here the same) exactly the same motion, one of the shafts must break as soon as they are put in motion.

The learner may exercise the rules on this circle, until he can form a similar circle of his own; and then he need never be afraid to undertake to calculate any motion, &c. afterwards.

I omit shewing the work for finding the motion of the several shafts in this circle, and the wheels to produce

said motion; but leave it for the learner to practise the rules on.

EXAMPLES.

1st. Given, the first mover AH 36 revolutions per minute, and first driver A 20 cogs, leader B 24; required, the revolutions of shaft BC. Answer, 30 revolutions per minute.

2d. Given, first mover 36 revolutions per minute, drivers 20—24—25, and leaders 24—30—30; required, the revolutions of the last leader. Answer, 20 revolutions per minute.

3d. Given, first mover 20 revolutions per minute, and first driver, strap-wheel, $14\frac{1}{2}$ inches, cog-wheel 12, and leader, strap-wheel, 30 inches, cog-wheel 29; required, the revolutions of the last leader, or last shaft. Answer, 4 revolutions.

4th. Given, first mover 36 revolutions, driver A 20, C 24, leader B 24, D 30; required, the number of leader F, to produce 20 revolutions per minute. Answer, 30 cogs.

5th. Given, first mover 36 revolutions per minute, driver A 20, C 24, E 25, driver pulley $14\frac{1}{2}$ inches diameter, L 12, and leader B 24, D 30, F 30, M 29; required, the diameter of strap-wheel K, to give shaft 4 four revolutions per minute. Answer, 30 inches diameter.

The learner may, for exercise, work the above questions, and every other that he can propose on the circle.

ART. 75.

Mathematicians have laid down the following proportions for finding the circumference of a circle by its diameter, or the diameter by the circumference given, viz.

As 1 is to 3,1416, so is the diameter to the circumference; and as 3,1416 is to 1, so is the circumference to the diameter: Or, as 7 is to 22, so is the diameter to the circumference; and as 22 is to 7, so is the circumference

to the diameter. The last proportion makes the diameter a little the largest; therefore it suits mill-wrights best for finding the pitch circle; because the sum of the distances, from centre to centre, of all the cogs in a wheel, makes the circle too short, especially where the number of cogs are few, because the distance is taken in straight lines, instead of the circle. In a wheel of 6 cogs only, the circle will be so much too short, as to give the diameter $\frac{2}{22}$ parts of the pitch or distance of the cogs too short. Hence we deduce the following

RULES FOR FINDING THE PITCH CIRCLE.

Multiply the number of cogs in the wheel, by the quarter inches in the pitch, and that product by 7, and divide by 22, and the quotient is the diameter in quarter inches, which is to be reduced to feet.

EXAMPLE.

Given, 84 cogs $4\frac{1}{2}$ inches pitch; required, the diameter of the pitch circle.

Then, by the rule, 84 multiplied by 18 and 7, is equal to 10584; which, divided by 22, is equal to $481\frac{2}{22}$ quarter inches, equal to 10 feet $\frac{1}{4}\frac{2}{22}$ inches, for the diameter of the pitch circle required.

ART. 76.

A true, simple, and expeditious method of finding the diameter of the pitch circle, is to find it in measures of the pitch itself that you use.

RULE.

Multiply the number of cogs by 7, and divide by 22, and you have the diameter of the pitch circle, in measures of the pitch, and 22 parts of said pitch.

EXAMPLE.

Given, 78 cogs; required, the diameter of the pitch circle. Then, by the rule,

78
7

---

22)546($24\frac{18}{22}$ } Measures of the pitch for the diameter of the circle required.
44

106
88

18

Half of which diameter. $12\frac{9}{22}$ of the pitch, is the radius, or half diameter, by which the circle is to be swept.

To use this rule, set a pair of compasses to the pitch, and screw them fast, not to be altered until the wheel is pitched; divide the pitch into 22 equal parts; then step 12 steps on a straight line with the pitch compasses, and 9 of these equal parts of the pitch makes the radius that is to describe the circle.

To save the trouble of dividing the pitch for every wheel, the workman may mark the different pitch, which he commonly uses, on the edge of his two foot rule (or make a little rule for the purpose) and carefully divide them there, where they will be always ready for use. See plate IV, fig. 35.

By these rules, I have calculated the following table of the radiuses of pitch circles of the different wheels commonly used, from 6 to 136 cogs.

A TABLE

OF THE

PITCH CIRCLES OF THE COGWHEELS

COMMONLY USED,

From 6 to 136 cogs, both in measures of the Pitch, and in feet, inches, and parts.

Cogs in the wheel.	Radius of the pitch circle in measures of the pitch and 22 parts and tenths of parts of said pitch.		Radius of the pitch circle of the wheels in column 1, taken in inches, quarters, and 22 parts of a quarter, when the pitch is 2¾ inches, for bolting gears, &c.			Cogs in the wheel.	Radius of the pitch circle in measures of the pitch and 22 parts of said pitch.		Radius of the pitch circle of the wheels in the 4th column, taken in feet, inches, quarters, and 22 parts of a quarter, when the pitch is 4¼ inches, for large gears, &c.				Ditto, when the pitch is 4½ inches.			
No.	Pitch.	22 parts.	inches.	quarters.	22 parts.	No.	Pitch.	22 parts.	feet.	inches.	quarters.	22 parts.	feet.	inches.	quarters.	22 parts.
6	1		2	2	0	33	5	5 1-2	1	10	1	5 1-2	1	11	2	11
7	1	3,5	2	3	12	34	5	9	1	10	3	21	2	0	1	8
8	1	6,7	3	1	3	35	5	12 1-2	1	11	2	14 1.2	2	1	0	5
9	1	10,2	3	2	14	36	5	16	2	0	1	8	2	1	3	2
10	1	13,6	4	0	3	37	5	19 1-2	2	1	0	1 1-2	2	2	1	21
11	1	17,1	4	1	17	38	6	1	2	1	2	17	2	3	0	10
12	1	20,5	4	3	5	39	6	4 1-2	2	2	1	10 1.2	2	3	3	15
13	2	1,9	5	0	17	40	6	8	2	3	0	4	2	4	2	12
14	2	5,3	5	2	8	42	6	15	2	4	1	13	2	6	0	6
15	2	8,8	5	3	20	44	7		2	5	3	0	2	7	2	0
16	2	12,2	6	1	11	48	7	14	2	8	1	18	2	10	1	10
17	2	15,7	6	3	2	52	8	4	2	11	0	14	3	1	0	20
18	2	19,1	7	0	15	54	8	11	3	0	2	1	3	2	2	14
19	3	0,6	7	2	6	56	8	20	3	1	3	10	3	4	0	8
20	3	4,1	7	3	18	60	9	13	3	4	2	6	3	6	3	18
21	3	7,5	8	1	9	66	10	11	3	8	2	11	3	11	1	0
22	3	11,	8	3	0	72	11	10	4	0	2	16	4	3	2	4
23	3	14,5	9	0	13	78	12	9	4	4	2	21	4	7	3	8
24	3	18,	9	2	4	84	13	8	4	8	3	4	5	0	0	12
25	3	21,5	9	3	17	88	14	0	4	11	2	0	5	3	0	0
26	4	3,	10	1	8	90	14	7	5	0	3	9	5	4	1	16
27	4	6,5	10	2	21	96	15	6	5	4	3	14	5	8	2	20
28	4	10,	11	0	12	104	16	13	5	10	1	6	6	2	1	18
29	4	13,5	11	2	3	112	17	18	6	3	2	20	6	8	0	16
30	4	17,	11	3	16	120	19	2	6	9	0	12	7	1	3	14
31	4	20,5	12	1	7	128	20	8	7	2	2	4	7	7	2	12
32	6	2,	12	2	20	136	21	14	7	7	3	18	8	1	1	10
1	2		3			4	5		6				7			

Use of the foregoing Table.

Suppose you are making a cog-wheel with 66 cogs; look for the number in the 1st or 4th column, and against it, in the 2d or 5th column, you find 10, 11; that is, 10 steps of the pitch (you use) on a straight line, and 11 of 22 equal parts of said pitch added, makes the radius that is to describe the pitch circle.

The 3d, 6th and 7th columns, contain the radius in feet, inches, quarters, and 22 parts of a quarter; which may be made use of in roughing out timber, and fixing the centres that the wheels are to run in, so that they may gear to the right depth; but, on account of the difference in the parts of the same scales or rules, and the difficulty of setting the compasses exactly, they can never be true enough for the pitch circles.

RULE COMMONLY PRACTISED.

Divide the pitch into 11 equal parts, and take in your compasses 7 of those parts, and step on a straight line, counting 4 cogs for every step, until you come up to the number in your wheel; if there be an odd one at last, take 1-4 of a step, if 2 be left, take 1-2 of a step, if 3 be left, take 3-4 of a step, for them; and these steps, added, makes the radius or sweep-staff of the pitch circle: but on account of the difficulty of making these divisions sufficiently exact, there is little truth in this rule—and where the number of cogs are few, it will make the diameter too short, for the reason mentioned before.

The following geometrical rule is more true and convenient, in some instances.

RULE.

Draw the line AB, plate IV. fig. 34, and draw the line 0,22 at random; then take the pitch in your compasses, and beginning at the point 22, step 11 steps towards A, and 3 1-2 steps to point X, towards O; draw the line AC through the point X; draw the line DC parallel to AB; and, without having altered your com-

passes, begin at point O, and step both ways, as you did on AB; then, from the respective points, draw the cross lines parallel to 0,22; and the distance from the point, where they cross the line AC, to the line AB, will be the radius of the pitch circles for the number of cogs respectively, as in the figure. If the number of cogs be odd, say 21, the radius will be between 20 and 22.

This will also give the diameter of all wheels, that have few cogs, too short; but where the number of cogs is above twenty, the error is imperceptible.

All these rules are founded on the proportion, as 22 is to 7, so is the circumference to the diameter.

ART. 77.

A TABLE OF ENGLISH DRY MEASURE.

Solid inches.				
33,6	Pint.			
268,8	8	Gallon.		
537,6	16	2	Peck.	
2150,4	64	8	4	Bushel

The bushel contains 2150,4 solid inches. Therefore, to measure the contents of any garner, take the following

RULE.

Multiply its length by inches, by its breadth in inches, and that product by its height in inches, and divide the last product by 2150,4, and it will quote the bushels it contains.

But to shorten the work decimally; because 2150,4 solid inches are 1,244 solid feet, multiply the length, breadth, and height in feet, and decimal parts of a foot by each other, and divide by 1,244; and it will quote the contents in bushels.

EXAMPLE.

Given, a garner 6,25 feet long, 3,5 feet wide, 10,5 feet high; required, its contents in bushels. Then, 6,25 multiplied by 3,5 and 10,5, is equal to 229,687; which, divided by 1,244, quotes 184 bushels and 6 tenths.

To find the contents of a hopper, take the following

RULE.

Multiply the length by the width at the top, and that product by one-third of the depth, measuring to the very point, and divide by the contents of a bushel, either in inches or decimals, as you have wrought, and the quotient will be the contents in bushels.

EXAMPLE.

Given, a hopper 42 inches square at top, and 24 inches deep; required, the contents in bushels.

Then 42 multiplied by 42 and 8, is equal to 14112 solid inches; which, divided by 2150,4, quotes 6,56 bushels, or a little more than $6\frac{1}{2}$ bushels.

To make a garner to hold any given quantity, having two of its sides given, take the following

RULE.

Multiply the contents of 1 bushel by the number of bushels the garner is to hold; then multiply the given sides into each other, and divide the first by the last product; and the quotient will be the side wanted, in the same measure you have wrought in.

EXAMPLE.

Given, two sides of a garner 6,25 by 10,5 feet; required, the other side, to hold 184,6 bushels.

Then, 1,244 multiplied by 184,6 is equal to 229,642; which, divided by the product of the two sides 65,625, the quotient is 3,5 feet for the side wanted.

To make a hopper to hold any given quantity, having the depth given.

RULE.

Divide the inches contained in the bushels it is to hold, by 1-3 the depth in inches; and the quotient will be the square of one of the sides at the top in inches. Given, the depth 24 inches; required, the sides to hold 6,56 bushels.

Then, 6,56 multiplied by 2150,4 is equal to 14107,624; which, divided by 8, quotes 1764, the square root of which is 42 inches; which is the length of the sides of the hopper wanted.

CHAPTER III.

ART. 78.

OF THE DIFFERENT KINDS OF GEARS, AND FORMS OF COGS.

IN order to conceive a just idea of the most suitable form or shape for cogs in cog-wheels, we must consider, that they describe with respect to the pitch circles, a figure called Epicycloid.

And when one wheel works in cogs set in a straight line, such as the carriage of a saw-mill, the cogs or rounds, moving out and in, form a curve figure called a Cycloid.

To describe which, let us suppose the large circle in plate V, fig. 37, to move on the straight line from O to A; then the point O in its periphery will describe the arch ODA, called a Cycloid; and we may conceive, by the way that the curve joins the line, what should be the form of the point of the cog.

Again, suppose the small circle to run round the large one; then the point o in the small circle, will describe the arch o b c, called an Epicycloid; by which we may conceive the form the point of the cogs should be. But in common practice, we generally let the cogs extend but a short distance past the pitch circle; so that the form of the cogs is not so particular.

ART. 79.

OF SPUR GEARS.

The principle of spur gears, is that of two cylinders rolling on each other, with their shafts or axes truly

parallel to each other. Here the touching parts move with equal velocity, therefore have but little friction. And to prevent these cylinders from slipping, we are obliged to indent them, or to set in cogs. And here it appears to me, that the pitch of the driving wheel should be a little larger than the leading wheel, for the following reasons :

1. If there is to be any slipping, it will be much easier for the driver to slip a little past the leader, than for the cogs to have to force the leader a little before the driver; which would be very hard on them.

2. If the cogs should bend any by the stress of the work (as they surely do; because 1lb. falling on a beam a foot square, will jar it, which cannot be done without bending it a little) this will cause those that are coming into gear to touch too soon, and rub hard at entering.

3. It is much better for cogs to rub hard as they are going out of gear, than as they are coming in; because then they work with the grain of the wood; whereas, at entering they work against it, and would wear much faster.

The advantage of this kind of gear is, we can make the cogs as wide as we please, so that their bearing may be so large that they will not cut each other, but only polish and wear smooth; therefore they will last a long time.

Their disadvantages are,

1st. That if the wheels be of different sizes, and the pitch circles are not made to meet exactly, they will not run smooth. And,

2d. We cannot change the direction of the shafts so conveniently.

Fig. 38, plate V, is two spur wheels working into each other; the dotted lines shew the pitch circles, which must always meet exactly. The ends of the cogs are made circular, as is common; but if they were made of the true epicycloids that would suit the size of the wheels, they would work smoother, with less friction.

Fig. 39, is a spur and face wheel or wallower; whose pitch circles should always meet exactly also.

The rule for describing the sides of the cogs of a form near the figure of an epicycloid, is as follows. viz. Describe a circle a little inside of the pitch circle, for the point of your compasses to be set in, so as to describe the sides of the cog as the four cogs at A, Plate V. fig. 38—39, as near as you can to the curve of the epicycloid that is formed by the little wheel's moving round the great one; the greater the difference between the great and small wheels, the greater distance must this circle be inside of the pitch circle; of this the practitioner is to be the judge, as no certain rules is yet formed, that I know of.*

ART. 80.

OF FACE GEARS.

The principle of face gears, is that of two cylinders rolling with the side of one on the end of the other, their axes being at right angles. Here the greater the bearing, and the less the diameter of the wheels, the greater will be the friction; because the touching parts move with different velocities, therefore the friction will be great.

The advantages of this kind of gear are,

1st. Their cogs stand parallel to each other; therefore moving them out or in gear a little, does not alter the

* Mr. Charles Taylor's rule for ascertaining the true cycloidical or epicycloidical form for the point of cogs.

Make a segment of the pitch circle of each wheel, which gear into each other: fasten one to a plane surface, and roll the other round it as shewn, plate V, fig. 37, art. 79, and with a point in the moveable segment, describe the epicycloid o b c, set off at the end o one-fourth part of the pitch for the length of the cog outside of the pitch circle. Then fix the compasses at such an opening, that with one leg thereof in a certain point (to be found by repeated trials,) the other leg will trace the epicycloid from the pitch circle to the end of the cog: preserve the set of the compasses, and through the point where the fixed leg stood, sweep a circle from the centre of the wheel, in which set one point of the compasses to describe the point of all the cogs of that wheel whose segment was made fast to the plane.

If the wheels be bevel gear, this rule may be used to find the true form of both the outer and inner ends of the cogs, especially if the cogs be long, as the epicycloid is different in different circles. In making cast-iron wheels, it is absolutely necessary to attend to forming the cogs to the true epicycloidical figure, without which they cannot work smooth and easy.

The same rule serves for ascertaining the cycloidical form of a right line of cogs, such as those of a saw-mill carriage, &c. or of cogs set inside of a circle or hollow cone; where a wheel works within a wheel, the cogs require a very different shape.

pitch of the bearing parts of the cogs, and they will run smoother when their centres are out of place, than spur gears.

2. They serve for changing the direction of the shafts.

The disadvantages are,

1st. The smallness of the bearing, so that they wear out very fast.*

2d. Their great friction and rubbing of parts.

The cogs for small wheels are generally round, and put in with round shanks. Great care should be taken in boring the holes for the cogs, with a machine to direct the auger straight, that the distance of the cogs may be equal, without dressing. And all the holes of all the small wheels in a mill should be bored with one auger, and made of one pitch; then the miller may keep by him a quantity of cogs ready turned, to a gauge to suit the auger, and when any fail, he can drive out the old ones, and put in a new set, without much loss of time.

Fig. 40, plate V, represents a face cog-wheel working into a trundle; shewing the necessity of having the corners of the sides of the cogs sniped off in a cycloidical form, to give liberty for the rounds to enter between the cogs, and pass out again freely. To describe the sides of the cogs of the right shape to meet the rounds when they get fairly into gear, as at c, there must be a circle described on the ends of the cogs, a little outside of the pitch circle, for the point of the compasses to be set in, to scribe the ends of the cogs; for if the point be set in the pitch circle, it will leave the inner corners too full, and make the outer ones too scant. The middle of the cog is to be left straight from bottom to top, or nearly so, and the side nearly flat at the distance of half the diameter of the round from the end, the corners only being sniped off to make the ends of the shape in the figure; because when the cog comes into gear fully, as at c, there is the chief stress, and there the bearing should be

* For if the bearing of the cogs be small, and the stress so great that they cut one another, they will wear exceedingly fast; but if it be so large, and the stress so light, that they only polish one another, they will last very long.

as large as possible. The smaller the cog-wheel, the larger the trundle, and the wider the cogs, the more will the corners require to be sniped off. Suppose the cog-wheel to turn from 40 to b, the cog 40, as it enters, will bear on the lower corner, unless it be sufficiently sniped off; when it comes to c, it will be fully in gear, and if the pitch of the cog-wheel be a little larger than that of the trundle, the cog a will bear as it goes out, and let c fairly enter before it begins to bear.

Suppose the plumb line A B to hang directly to the centre of the cog-wheel, the spindle is (by many mill-wrights) set a little before the line or centre, that the working round or stave of the trundle may be fair with said line, and meet the cog fairly as it comes to bear: it also causes the cogs to enter with less, and go out with more friction. Whether there be any real advantage in thus setting the spindle foot before the centre plumb line, does not seem determined.

ART. 81.

OF BEVEL GEARS.

The principle of bevel gears, is that of two cones rolling on the surface of each other, their vertexes meeting in a point, as at A, fig. 41, plate V. Here the touching surfaces move with equal velocities in every part of the cones; therefore there is but little friction. These cones being indented, or fluted with teeth diverging from the vertex to the base, to prevent them from slipping, become bevel gear; and as these teeth are very small at the point or vertex of the cone, they may be cut off 2 or 3 inches from the base, as 19 and 25, at B; they then have the appearance of wheels.

To make these wheels of a suitable size for any number of cogs you choose to have to work into one another, take the following

RULE.

Draw lines to represent your shafts, in the direction they are to be, with respect to each other, to intersect at

A; then take from any scale of equal parts, either feet, inches or quarters, &c. as many as your wheels are to have cogs, and at that distance from the respective shafts, draw the dotted lines a b, c d, for 21 and 20 cogs; and from where they cross at e, draw e A. On this line, which makes the right bevel, the pitch circles of the wheels will meet, to contain that proportion of cogs of any pitch.

Then to determine the size of the wheels to suit any particular pitch, take from the table of pitch circles, the radius in measures of the pitch, and apply it to the centre of the shaft, and the bevel line A e, taking the distance at right angles with the shaft; and it will show the point in which the pitch circles will meet, to suit that particular pitch.

By the same rule, the sizes of the wheels at B and C are found.

These kind of wheels are frequently made of cast metal, and do exceedingly well.

The advantages of this kind of gear are,

1. They have very little friction, or sliding of parts.

2. We can make the cogs of any width of bearing we choose; therefore they will wear a great while.

3. By them we can set the shafts in any direction desired, to produce the necessary movements.

Their disadvantages are,

1. They require to be kept exactly of the right depth in gear, so that the pitch circles just meet, else they will not run smooth, as is the case with spur gears.

2. They are expensive to make of wood; therefore few in this country use them.

The universal joint, as represented fig. 43, may be applied to communicate motion, instead of bevel gear, where the motion is to be the same, and the angle not more than 30 or 40 degrees. This joint may be constructed by a cross, as in the figure, or by 4 pins fastened at right angles on the circumference of a hoop or solid ball. It may sometimes serve to communicate the motion, instead of 2 or 3 face wheels. The pivots at the end of the cross play in the ends of the semicircles. It

is best to screw the semicircles to the blades, that they may be taken apart.

ART. 82.

OF MATCHING WHEELS, TO MAKE THE COGS WEAR EVEN.

Great care should be taken in matching or coupling the wheels of a mill, that their number of cogs be not such that the same cogs will often meet; because if two soft ones meet often, they will both wear away faster than the rest, and destroy the regularity of the pitch; whereas if they are continually changing, they will wear regular, even if they are at first a little irregular.

For finding how often they will revolve before the same cogs meet again, take the following

RULE.

1. Divide the cogs in the greater wheel by the cogs in the lesser; and if there be no remainder, the same cogs will meet once every revolution of the great wheel.

2. If there be a remainder, divide the cogs in the lesser wheel by the said remainder; and if it divide them equally, the quotient shows how often the great wheel will revolve before the same cogs meet.

3. But if it will not divide equally, then the great wheel will revolve as often as there are cogs in the small wheel, and the small wheel as often as there are cogs in the large wheel, before the same cogs meet: oftener they can never be made to change.

EXAMPLES.

1. Given, wheels 13 and 17 cogs; required, how often each will revolve before the same cogs meet again.

Then 13)17(1
13
—
4)13(3
12 — Answer,
— — Great wheel 13, and
1 — Small do. 17 revs.

ART. 83.

THEORY OF ROLLING SCREENS AND FANS, OR WIND-MILLS FOR SCREENING AND FANNING THE WHEAT IN MILLS.

Let fig. 42, plate V, represent a rolling screen and fan, fixed for cleaning wheat in a merchant-mill. DA the screen, AF the fan, AB the wind tube, 3 feet deep from A to b, and 4 inches wide, in order that the grain may have a good distance to fall through the wind, to give time and opportunity for the light parts to be carried forward before the heavy parts. Suppose the tube to be of equal depth and width the whole of its length, except where it communicates with the tight boxes or garners under it, viz. c for the clean wheat, S for the screenings and light wheat, and C for the cheat, chaff, &c. Now it is evident, if wind be by the fan drove into the tube at A, that if it can escape no where, it will pass on to B, with the same force as at A, let the tube be of any length or direction; and any thing which it will move at A, it will carry out at B, if the tube be of an equal size all the way.

It is also evident, that if we shut the holes of the fan at A and F, and let no wind into it, none can be forced into the tube; hence, the best way to regulate the blast is, to fix shutters sliding at the air holes, to give more or less feed or air to the fan, so as to produce a blast sufficient to clean the grain.

The grain is let into the screen at D, into the inmost cylinder, in a small stream. The screen consists of two cylinders of sieve wire, the inmost one has the meshes so open, as to pass all the wheat through it to the outer one, retaining only the white caps, large garlic, and every thing larger than the grain of the wheat, which falls out at the tail A.

The outer cylinder is so close in the mesh, as to retain all good wheat, but sift out the cheat, cockle, small wheat, garlic, and every thing less than good grains of wheat; the wheat is delivered out at the tail of the outer cylinder, which is not quite as long as the inner one,

where it drops into the wind tube at a, and as it falls from a to b, the wind carries off every thing lighter than good wheat, viz, cheat, chaff, light garlic, dust, and light rotten grains of wheat; but, in order to effect this more completely, it should fall at least 3 feet through the current of wind.

The clean wheat falls into the funnel b, and thence into the garner c, over the stones. The light wheat, screenings, &c. fall into garner S, and the chaff settles into the chaff room C. The current slackens passing over this room, and drops the chaff, but resumes its full force as soon as it is over, and carries out the dust through the wall at B. To prevent the current from slackening too much as it passes over S and c, and under the screen, make the passages, where the grain come in and goes out, as small as possible, not more than half an inch wide, and as long as necessary. If the wind escapes any where but at B, it defeats the scheme, and carries out the dust into the mill. Or fix valves to shut the passages by a weight or spring, so that the weight of the wheat, &c. falling on, will open them just enough to let it pass, without suffering any wind to escape.*

Note, the fan is set to blow both the wheat and screenings, and carry the dust out.

Note also, That the wind cannot escape into the garners or screen room, if they are tight; for as soon as they are full, no more can enter.

By attending duly to the foregoing principle, we may fix fans to answer our purposes.

The principal things to be observed in fixing screnes and fans, are,

1. Give the screen 1 inch to the foot fall, and between 15 and 18 revolutions in a minute.

2. To make the fan blow strong enough, let the wings be 3 feet wide, 20 inches long, and revolve 140 times in a minute.

3. Then regulate the blast, by giving more or less feed of wind.

* This I have from Timothy Kirk, being one principle of his improved fan.

4. Leave no place for the wind to escape, but at the end through the wall.

5. Wherever you want it to blow hardest, there make the tube narrowest.

6. Where you want the chaff and cheat to fall, there make the tube sufficiently wider.

7. Make them blow both the wheat and screenings, and carry the dust clear out of the mill.

8. The wind tube may be of any length, and either crooked or straight, as may best suit; but no where less than where the wheat falls.

CHAPTER IV.

ART. 84.

OF GUDGEONS, THE CAUSE OF THEIR HEATING AND GETTING LOOSE, AND REMEDIES THEREFOR.

THE cause of gudgeons heating, is the excessive friction of their rubbing parts, which generates the heat in proportion to the weight that passes the rubbing surfaces together, and the velocity with which they move. See art. 31.

The cause of their getting loose is, their heating, and burning the wood, or drying it, so that it shrinks in the bands, and gives the gudgeon room to work.

To avoid the effects, we must remove the causes.

1. Increase the surface of contact or rubbing parts, and, if possible, decrease their velocity; the heat will not then be generated so much.

2. Conduct the heat away from the gudgeon as fast as generated, if possible.

To increase the surface of contact, without increasing its velocity, make the neck or bearing part of the gudgeon longer. If the length be doubled, the weight will be sustained by a double surface, and velocity the same; there will not then be so much heat generated: and even

supposing the same quantity of heat generated, there will be a double space of surface exposed to air, to convey it away.*

To convey the heat away as fast as generated, cause a small quantity of water to drop slowly on the gudgeon, to carry off the heat by evaporation.† A small quantity is better than a large; because it should be just sufficient to keep up the evaporation, and not destroy the polish made by the grease; which it will do if the quantity be too great, and will let the bear box and gudgeon come in contact; which will cause both to wear away very fast.‡

The best form that I have seen for large gudgeons for heavy wheels, is made of cast iron. Fig. 6, plate XI. is a perspective view of one; a a a a, are four wings at right angles with each other, extending from side to side of the shaft. These wings are larger, every way, at the end that is farthest in the shaft, than at the outer end, for convenience in casting them, and also that the bands may drive on tight, one over each end of the wings. Fig. 4, is an end view of the shaft, with the gudgeon in it, and a band on the end; these bands, be-

* To understand this subject better, let us consider, that when we strike a flint with steel, we choose the sharpest part of the flint; then the surface of contact is so small, that the force of the stroke creates friction enough to strike or generate fire; but if we strike a thick smooth part of the flint, the force will not be sufficient to strike fire, the surface being too large. Hence we may conclude, that the smaller the rubbing surface, the greater the heat; and if the surface was so small as to strike fire continually, it would be very difficult to keep the gudgeon cool. If a gudgeon heats at 3 inches bearing on the box, lengthen it to 6 or 8 inches. I have seen them in use from 2 1-2 to 10 inches bearing on the box; and those who had the longest (being men of the greatest experience in the milling business) accounted their length to be a good remedy against the heating.

† Water is a great conductor of heat, and wonderful is the effect of the principle of evaporation, in carrying off the heat from bodies; every particle of water that evaporates, carries off a quantity of heat with it. Dr. Franklin asserts, that by evaporation a man could be froze to death the warmest day in summer.

‡ The grease operates in lessening friction, perhaps in three ways. 1st. The particles of the grease, by filling up the pores of the box and gudgeon, makes the sliding surface more perfectly smooth. 2. The particles of grease act as rollers between the sliding surfaces. 3. It destroys the cohesion that might otherwise take place between the surfaces. See art. 31, and 33.

Oil is said to answer best for spindle feet and step gudgeons, tallow for common gudgeons, and black lead mixt with tallow for cogs, which forms a glossy polish on them that will wear a long time.

ing put on hot, become very tight as they cool, and if the shaft is dry will not get loose; but will if it is green: but by driving a few wedges along side of each wing, it can be easily fastened, by any ordinary hand, without danger of moving it much from the centre.

One great use of these wings is, to convey away the heat from the gudgeon to the bands, which are in contact with the air; and by thus distributing the heat through so much metal, with so large a surface exposed to the air, the heat is carried off as fast as generated; therefore can never accumulate to a degree sufficient to burn loose, as it will often do in common gudgeons of wrought iron. Wood will not conduct the heat as well as the wings of metal; therefore it accumulates in the small space of the gudgeon, to such a degree as to burn loose.

These gudgeons should be made of the best hard metal, well refined, in order that they may wear well, and not be subject to break; but of this there is but little danger, if the metal is good: should it prove to be the case, I propose to have wings cast separate from the neck, as represented by fig. 4: where the inside light square shows a mortise for the steeled gudgeon, Plate XI. fig. 8, to be fitted into, with an iron key behind the wings, to draw the gudgeon in tight, if ever it should work loose; by which means it may be taken out, at any time, to repair.

This plan would do well for step gudgeons for heavy upright shafts, such as tub-mills, &c.

When the neek is cast with the wings, the square part in the shaft need not be larger than the light square representing the mortise.*

* Grease of any kind used to the drill, in boring cast iron, prevents it from cutting, but on the contrary will make it cut wrought iron or steel much faster. This quality in cast iron renders it most suitable for gudgeons, and may be the principal cause why cast iron gudgeons have proved much better than any one expected. Several of the most experienced and skilful mill-wrights and millers do assert that they have experienced cast gudgeons to run on cast boxes better than on stone or brass, in one instance carrying heavy overshot wheels which turned seven feet millstones. They have run ten years, doing much work, and have hardly worn off the sand marks; may we not expect them to last ten times as

CHAPTER V.

ART. 85.

ON BUILDING MILL-DAMS, LAYING FOUNDATIONS, AND BUILDING MILL-WALLS.

THERE are several things to be considered, and dangers to be guarded against, in building mill-dams.

1. Construct them so, that the water, tumbling over them, cannot undermine their foundations at the lower side.*

2. So that heavy logs, large pieces of ice, &c. floating down, cannot catch against any part of them, but slide easily over.†

long, and make up 100 years? In other instances they have worn out in a few days, and let the wheel drop, owing no doubt, to their being made of unsuitable metal or wrongly tempered.

* If you have not a foundation of solid rocks, or so heavy, that the water tumbling over, will never move them, there should be such a foundation made with great stones, not lighter than mill-stones (if the stream is heavy, and the tumble great) well laid, as low and close as possible, with their upstream end lowest, to prevent any thing from catching under them. But if the bottom is sand or clay, make a foundation of the trunks of long trees, laid close together on the bottom of the creek, with their butt ends down stream, as low and close as possible, across the whole tumbling space. On these may be built the dam, either of stone or wood, leaving 12 or 15 feet below the breast or fall, for the water to fall upon. See fig. 3, plate X, which is a front view of a log dam, showing the position of the logs, also of the stones in the abutments.

† If the dam is built of timber and small stones, &c. make the breast perpendicular of straight logs, laid close one upon another, putting the largest, longest, and best logs on the top; make another wall of logs 12 or 15 feet upstream, laying them close together, to prevent lamprey eels from working through them, not so high as the other, by 3 feet; tie these walls together, at every 6 feet, with cross logs, with the butts down stream, dovetailed and bolted strongly to the logs of the lower wall, especially the upper log, which should be strongly bolted down to them. The spaces between these log walls, are to be filled up with stones, gravel, &c. Choose a dry season for this work; then the water will run through the lower part while you build the upper part tight.

To prevent any thing from catching against the top log, flag the top of the dam with broad or long stones, laying the downstream end on the upstream side of the log, to extend a little above it, the other end lowest, so that the next tier of stones will lap a little over the first; still getting lower as you advance upstream. This will glance logs, &c. over the dam, without catching against any thing. If suitable stones cannot be had, I would recommend strong plank, or small logs, laid close together, with both ends pinned to the top logs of the wall, the upstream end being 3 feet lower than the other: But if plank is to be used, there need only be a strong frame raised on the

3. So that the pressure or force of the current of the water will press their parts more firmly together.*

4. Give them a sufficient tumbling space to vent all the water in time of freshets.†

5. Make the abutments so high, that the water will not overflow them in time of freshets.

6. Let the dam and mill be a sufficient distance apart; so that the dam will not raise the water on the mill, in time of high floods.‡

foundation logs, to support the plank or the timber it is pinned to. See a side view of this frame, fig. 45, plate IV. Some plank the breast to the front posts, and fill the hollow space with stone and gravel; but this may be omitted, if the foundation logs are sufficiently long upstream, under the dam, to prevent the whole from floating away. Stone first, and then gravel, sand, and clay, are to be filled in above this frame, so as to stop the water. If the abutments are well secured, the dam will stand well.

General Ira Allen, of the state of Vermont, ascertained by experiment, that a plank laid in a current of water, with the upstream end lowest set at an angle of 22 1-2 degrees with the horizon or current of the water, will be held firmly to its place by the force of the current, and in this position it requires the greatest force to remove it, and the stronger the current the firmer it is held to its place, that is, supposing there remains a partial vacuum under the plank, this points out the best position for the breast of dams.

* If the dam is built of stone, make it in the form of an arch or semicircle, standing upstream, and endeavour to fix strong abutments on each side, to support the arch; then, in laying the stones, put the widest end upstream, and the more they are drove downstream, the tighter they will press together. All the stones of a dam should be laid with their upstream ends lowest, and the other end lapped over the preceding, in manner of the shingles or tiles of a house, to glance every thing smoothly over, as at the side 3, of fig. 3, plate X. The breast may be built up with stone, either on a good rock or log foundation, putting the best in front, leaning a little upstream, and on the top lay one good log, and another 15 feet upstream on the bottom, to tie the top log to, by several logs, with good butts, downstream, dovetailed and bolted strongly, both at bottom and top of the top and upstream logs; fill in between them with stone and gravel, laying large stones slanting next the top log, to glance any thing over it. This will be much better than to build all of stone; because if one at top give way, the breach will increase rapidly, and the whole go down to the bottom.

† If the tumbling space is not long enough, the water will be apt to overflow the abutments, and if they are earth or loose stones, they will be broken down, and perhaps a very great breach made. If the dam is of logs, the abutments had best be made of stone, laid as at the side 3, in fig. 3; but if stone is not to be had, they must be made of wood, although subject to rot soon, being above water.

‡ I have, in many instances, seen the mill set so close to the dam, that the pier-head or forebay was in the breast; so that in case of a leak or breach about the forebay or mill, there is no chance of shutting off the water, or conveying it another way; but all must be left to its fate. The mill is frequently broken down, and carried away; even the mill-stones are carried a considerable distance down the stream, and sometimes buried under the sand, and never found.

ART. 86.

ON BUILDING MILL-WALLS.

The principal things to be considered in building mill-walls, are,

1. To lay the foundations with good large stones, so deep as to be out of danger of being undermined, in case of any accident of the water breaking through at the mill.*

2. Set the centre of gravity, or weight of the wall, on the centre of its foundation.†

The great danger of this error will appear more plain, if we suppose six mills on one stream, one above the other, each at the breast of the dam; and a great flood to break the first or uppermost dam, say through the pierhead, carrying with it the mill, stones and all; this so increases the flood, that it overflows the next dam, which throws the water against the mill, and it is taken away; the water of these two dams has now so augmented the flood, that it carries every mill before it, until it comes to the dam of the sixth, which it sweeps away also; but suppose this dam to be a quarter of a mile above the mill, which is set well into the bank, the extra water that is thrown into the canal, runs over at the waste left in its banks for the purpose; and the water having a free passage by the mill, does not injure it; whereas, had it been at the breast of the dam, it must have went away with the rest. A case similar to this, actually happened in Virginia in 1794; all the mills and dams on Falling Creek, in Chesterfield county, were carried away at once, except the lowest, (Mr. Wardrope's:) whose dam, having broke the year before, was rebuilt a quarter of a mile higher up; by which means his mill was saved.

* If the foundation is not good, but abounding with quicksands, the wall cannot be expected to stand, unless it be made good by driving down piles until they meet the solid ground; on the top of which may be laid large flat pieces of timber, for the walls to be built on; they will not rot under water, totally excluded from the air.

† It is a common practice to build walls plumb outside, and batter them all from the inside; which throws the centre of their gravity to one side of their base. See art. 14. Therefore if it settles any, it will incline to fall outwards. Mill-walls should be battered as much outside, as to be equal to the offsets inside, to cause the whole weight to stand on the centre of the foundation, unless it stand against a bank, as the wall next the wagon, in plate VIII. The bank is very apt to press the wall inwards, unless it stands battering. In this case, build the side against the bank plumb, even with the ground, and then begin to batter it inwards. The plumb rules should be made a little widest at the upper end, so as to give the wall the right inclination, according to its height; to do which, take a line, the length equal to the height of the wall, set one end, by a compass point, in the lower end of the plumb rule, and strike the plumb line; then move the other end just as much as the wall is to be battered in the whole height: and it will show the inclination of the side of the rule that will batter the wall exactly right. This error of building walls plumb outside, is frequently committed in building the abutments of bridges; the consequence is, they fall down in a short time;

3. Use good mortar, and it will, in time, petrify and become as hard as stone.*

4. Arch over all the windows, doors, &c.

5. Tie them well together by the timbers of the floors.

because the earth between the walls is expanded a little by every hard frost, and tumbles the walls over.

* I have but little experience in this; but will quote an experienced author (George Sample, on Free Trade.) He says,

"Concerning Lime, Mortar, and Grout.

"I have, from my childhood, been well acquainted with the nature of lime and sand made into mortar, of all sorts that have been used in buildings in these countries, and tried numerous experiments with them. On which, together with what I have observed and learned from old experienced workmen, during the course of upwards of sixty years, I think I can safely affirm, that good mortar, that is made of pure and well-burnt limestone, properly made up with sharp clean sand, free from any sort of earth, loam or mud, will, within some considerable time, actually petrify, and, as it were, turn to the consistence of a stone. I remember I had one of my remarks from an old Scotch mason; which I shall give you in his own identical words; that is,

"When a hundred years are past and gane,
"Then gude mortar is grown to a stain (or stone.)

"I need not explain what I mean by sharp clean sand; but I shall give you this one caution, that it is better to put too much sand in your mortar, than too little. I know workmen choose their mortar rich, because it works pleasanter; but rich mortar will not stand the weather so well, nor grow so hard, as poor mortar will do. If it was all lime, it would have no more strength, in comparison, than clay."

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PART III.

CONTAINING

EVANS'S PATENTED IMPROVEMENTS

ON THE

ART OF MANUFACTURING GRAIN INTO MEAL AND FLOUR.

INTRODUCTION.

THESE improvements consist of the invention, and various applications, of the following machines, viz.

1. The Elevator.
2. The Conveyer.
3. The Hopper-boy.
4. The Drill.
5. The Descender.

Which five machines are variously applied, in different mills, according to their construction, so as to perform every necessary movement of the grain and meal, from one part of the mill to another, or from one machine to another, through all the various operations, from the time the grain is emptied from the wagoner's bag, or from the measure on board the ship, until it is completely manufactured into superfine flour, and other different qualities, and completely separated, ready

for packing into barrels, for sale or exportation. All which is performed by the force of the water, without the aid of manual labour, except to set the different machines in motion, &c. Which lessens the labour and expense of attendance of flour mills, fully one-half. See the whole applied, plate VIII.

THE YOUNG MILL-WRIGHT'S GUIDE.

PART THE THIRD.

CHAPTER I.

DESCRIPTION OF MACHINES.

ART. 88.

1. *Of the Elevator.*

THE elevator is an endless strap, revolving over two pullies, one of which is set where the grain or meal, &c. is to be hoisted from, and the other where it is to be hoisted to; to this strap is fastened a number of small buckets, which fill themselves as they pass under the lower pulley, and empty as they pass over the upper one. To prevent waste of what may spill out of these buckets, the strap, buckets and pullies, are all enclosed, and work in tight cases; so that what spills will descend to the place from whence it was hoisted. A B, in fig. 1, plate VI, is an elevator for raising grain, which is let in at A, and discharged at B into the spouts leading to the different garners. Fig. 2 is a perspective of the strap and different kinds of buckets, and the various modes of fastening them to the strap.

2. *Of the Conveyer.*

The conveyer K I, plate VI, fig. 1, is an endless screw of two continued spires, put in motion in a trough; the

grain is let in at one end, and the screw drives it to the other, or collects it to the centre, as at y, to run into the elevator, (see plate VIII, 37—36—4, and 44—45) or it is let in at the middle, and conveyed each way, as 15—16, plate VIII.

Plate VI, fig. 3, is a top view of the lower pulley of a meal elevator in its case, and a meal conveyer in its trough, for conveying meal from the stones, as fast as ground, into the elevator. This is an 8 sided shaft, set on all sides with small inclining boards, called flights, for conveying the meal from one end of the trough to the other; these flights are set in a spiral line, as shown by the dotted line; but being set across said line, changes the principle of the machine from a screw to that of ploughs, which is found to answer better for conveying warm meal.

Besides these conveying flights, half their number of others are sometimes necessary; which are called lifters, and set with their broadsides foremost, to raise the meal from one side, and let it fall on the other side of the shaft to cool; these are only used where the meal is hot, and the conveyer short. See 21—22, in plate VIII; which is a conveyer, carrying the meal from 3 pair of stones to the elevator, 23—24.

3. *Of the Hopper-boy.*

Fig. 12, plate VII, is a hopper-boy; which consists of a perpendicular shaft, A B, put in a slow motion (not above 4 revolutions in a minute) carrying round with it the horizontal piece C D, which is called the arms, and set on the under side, full of small inclining boards, called flights, so set as to gather the meal towards the centre, or spread it from the centre to that part of the arm which passes over the bolting hopper; at which part, one board is set broadside foremost, as E, (called the sweeper) which drives the meal before it, and drops it into the hoppers H H, as the arms pass over them. The meal is generally let fall from the elevator, at the extremity of the arm, at D, where there is a sweeper, which drives the meal before it, trailing it in a circle the whole way round, so as to discharge nearly the whole of its load, by the time it returns

to be loaded again: the flights then gather it towards the centre, from every part of the circle; which would not be the case, if the sweepers did not lay it round; but the meal would be gathered from only one side of the circle. These sweepers are screwed on the back of the arm, so that they may be raised or lowered, in order to make them discharge sooner or later, as necessary.

The extreme flight of each end of the arms are put on with a screw passing through its centre, so that they may be turned to drive the meal outwards; the use of which is, to spread the warm meal as it falls, from the elevator, in a ring round the hopper-boy, while it at the same time gathers the cool meal into the bolting hopper; so that the cold meal may be bolted, and the warm meal spread to cool, by the same machine, at the same time, if the miller chooses so to do. The foremost edge of the arms is sloped up, in order to make them rise over the meal, and its weight is nearly balanced by the weight w, hung to one end of a cord, passing over the pulley P, and to the stay iron F. About $4\frac{1}{2}$ feet of the lower end of the upright shaft is made round, passing loosely through a round hole in the flight arm, giving it liberty to rise and fall freely, to suit any quantity of meal under it. The flight arm is led round by the leading arm L M, by a cord passing through the holes L M, at each end, and made fast to the flight arm D C. This cord is lengthened or shortened by a hitch-stick N, with two holes for the cord to pass through, the end of the cord being passed through a hole at D, and fastened to the end of a stick; this cord must reeve freely through the holes at the end of the arms, in order that the ends may both be led equally. The flight arm falls behind the leader about 1-6th part of the circle. The stay-iron C F E, is a ring at F, which fits the shaft loosely, and is for keeping the arm steady, and hanging the ends of an equal height by the screws C E.

Plate VII, fig. 13, is a perspective view of the under side of the flight arms. The arm a c, with flights and sweepers complete; s s s shews the screws which fasten the sweepers to the arms. The arm c-b, is to shew the rule for laying out for the flights. When the sweeper at

b, is turned in the position of the dotted line, it drives the meal outwards. Plate VII, fig. 14, is a plate on the bottom of the shaft, to keep the arm from the floor, and 15 is the step gudgeon.

4. *Of the Drill.*

The drill is an endless strap revolving over two pullies, like an elevator, but set nearly horizontal, and instead of buckets, there are small rakes fixed to the strap, which draw the grain or meal along the bottom of the case. See G H, in plate VI, fig. 1. The grain is let in at H, and discharged at G. This can sometimes be applied with less expense than a conveyer; if it is set a little descending, it will move grain or meal with ease, and will do well a little ascending.

5. *Of the Descender.*

The descender is a broad endless strap of very thin pliant leather, canvas, or flannel, &c. revolving over two pullies, which turn on small pivots, in a case or trough, to prevent waste, one end of which is to be lower than the other. See EF, plate VI, fig. 1. The grain or meal falls from the elevator on the upper strap, at E, and by its own gravity and fall, sets the machine in motion, and it discharges the load over the lower pulley F. There are two small buckets to bring up what may spill or fall off the strap, and lodge in the bottom of the case.

This machine moves on the principles of an overshot water-wheel, and will convey meal a considerable distance, with a small descent. Where a motion is easily obtained from the water, it is to be preferred to that of working itself, it being easily stopped, is apt to be troublesome.

The crane spout is hung on a shaft to turn on pivots or a pin, so that it may turn every way like a crane; into this spout the grain falls from the elevator, and, by turning, it can be directed into any garner. The spout is made to fit close, and play under a broad board, and the grain is let into it through the middle of this board, near the pin, so that it will always enter the spout. See it under B, plate VI, fig. 1. L is a view of the under side of it, and M is a top view of it. The pin or shaft may reach down so low, that a man may stand on the floor and turn it by the handle x.

CHAPTER II.

ART. 89.

APPLICATION OF THE MACHINES, IN THE PROCESS OF MANUFACTURING WHEAT INTO SUPERFINE FLOUR.

PLATE VIII, is not meant to shew the plan of a mill; but merely the application and use of the patented machines.

The grain is emptied from the wagon into the spout 1, which is set in the wall, and conveys it into the scale 2, that is made to hold 10, 20, 30, or 60 bushels, at pleasure.

There should, for the convenience of counting, be weights of 60lbs. each; divided into 30, 15, and 7½lbs. then each weight would show a bushel of wheat, and the smaller ones halves, pecks, &c. which any one could count with ease.

When the wheat is weighed, draw the gate at the bottom of the scale, and let it run into the garner 3; at the bottom of which there is a gate to let it into the elevator 4—5, which raises it to 5, and the crane spout being turned over the great store garner 6, which communicates from floor to floor, to garner 7, over the stones 8, which suppose to be for shelling or rubbing the wheat, before it is ground, to take off all dust that sticks to the grain, to break smut or fly-eaten grain, lumps of dust, &c. As it is rubbed it runs, by the dotted lines, into 3 again; in its passage it goes through a current of wind blowing into the tight room 9, having only the spout a, through the lower floor, for the wind to escape; all the chaff will settle in the room, but most of the dust passes out with the wind at a. The wheat again runs into the elevator at 4, and the crane spout, at 5, is turned over the screen hoppers 10 or 11, and the grain lodged there, out of which it runs into the rolling screen 12, and descends through the current of wind made by the fan 13; the clean heavy grain descends, by 14, into the conveyer 15—16, which conveys it into all the garners over the

stones 7—17—18, and these regularly supply the stones 8—19—20, keeping always an equal quantity in the hoppers, which will cause them to feed regularly; as it is ground the meal falls to the conveyer 21—22, which collects it to the meal elevator, at 23, and it is raised to 24, whence it gently runs down the spout to the hopper-boy at 25, which spreads and cools it sufficiently, and gathers it into the bolting hoppers, both of which it attends regularly; as it passes through the superfine cloths 26, the superfine flour falls into the packing chest 28, which is on the second floor. If the flour is to be loaded on wagons, it should be packed on this floor, that it may conveniently be rolled into them; but if the flour is to be put on board a vessel, it will be more convenient to pack on the lower floor, out of chest 29, and roll it into the vessel at 30. The shorts and bran should be kept on the second floor, that they may be conveyed by spouts into the vessel's hold, to save labour.

The rublings which fall from the tail of the 1st reel 26, are guided into the head of the 2d reel 27; which is in the same chest, near the floor, to save both room and machinery. On the head of this reel is 6 or 7 feet of fine cloth, for tail flour, and next to it the middling stuff, &c.

The tail flour which falls from the tail of the 1st reel 26, and head of the 2d reel 27; and requires to be bolted over again, is guided by a spout, as shown by dotted lines 21—22, into the conveyer 22—23, to be hoisted again with the ground meal; a little bran may be let in with it, to keep the cloth open in warm weather—But if there be not a fall sufficient for the tail flour to run into the lower conveyer, there may be one set to convey it into the elevator, as 31—32. There is a little regulating board, turning on the joint x under the tail of the first reels, to guide more or less with the tail flour.

The middlings, as they fall, are conveyed into the eye of either pair of mill-stones by the conveyer 31—32, and ground over with the wheat; which is the best way of grinding them, because the grain keeps them from being killed, and there is no time lost in doing it, and they are regularly mixed with the flour. There is a slanting sliding board, to guide the middlings over the

conveyer, that the miller may take only such part, for grinding over, as he shall judge fit: and a little regulating board between the tail flour and middlings, to guide more or less into the stones or elevator.

The light grains of wheat, screenings, &c. after being blown by the fan 13, fall into the screenings garner 32; the chaff is driven further on, and settles in the chaff-room 33; the greater part of the dust will be carried out with the wind through the wall. For the theory of fanning wheat, see art. 83.*

To clean the Screenings.

Draw the little gate 34, and let them into the elevator at 4, and be elevated into garner 10; then draw gate 10, and shut 11 and 34, and let them pass through the rolling-screen 12 and fan 13, and as they fall at 14, guide them down a spout (shown by dotted lines) into the elevator at 4, and elevate them into the screen-hopper 11; then draw gate 11, shut 10, and let them take the same course over again, and return into garner 10, &c. as often as necessary, and, when cleaned, guide them into the stones to be ground.

The screenings of the screenings are now in garner 32, which may be cleaned as before, and an inferior quality of meal made out of them.

By these means the wheat may be effectually separated from the seed of weeds, &c. saved for food for cattle.

This completes the whole process from the wagon to the wagon again, without manual labour, except in packing the flour, and rolling it in.

* The bolting-reels may all be set in a line connected by joint gudgeons, supported by bearers. The meal, as it leaves the tail of one reel, may be introduced into the head of the other, by an elevator bucket fixed on the head of the reel open at the side next the centre, so that it will dip up the meal, and as it passes over the centre drop in. This improvement was made by Mr. Jonathan Ellicott, and by it in many cases many wheels and shafts, and much room may be saved, and suit the convenience of the house, &c.

ARTICLE 90.

OF ELEVATING GRAIN FROM SHIPS.

If the wheat comes to the mill by ships, No. 35, and requires to be measured at the mill, then a conveyer, 35—4, may be set in motion by the great cog-wheel, and may be under or above the lower floor, as may best suit the height of the floor above high water. This conveyer must have a joint, as 36, in the middle, to give the end that lays on the side of the ship, liberty to raise and lower with the tide. The wheat, as measured, is poured into the hopper at 35, and is conveyed into the elevator at 4; which conveyer will so rub the grain as to answer the end of rubbing stones. And, in order to blow away the dust, when rubbed off, before it enters the elevator, part of the wind made by the fan 13, may be brought down by a spout, 13—36, and, when it enters the case of the conveyer, will pass each way, and blow out the dust at 37 and 4.

In some instances, a short elevator, with the centre of the upper pulley, 38, fixed immoveable, the other end standing on the deck, so much aslant as to give the vessel liberty to raise and lower, the elevator sliding a little on the deck. The case of the lower strap of this elevator must be considerably crooked, to prevent the points of the buckets from wearing by rubbing the descent. The wheat, as measured, is poured into a hopper, which lets it in at the bottom of the pulley.

But if the grain is not to be measured at the mill, then fix the elevator 35—39, to take it out of the hole, and elevate it into any door convenient. The upper pulley is fixed in a gate that plays up and down in circular rabbits, to raise and lower to suit the tide and depth of the hole to the wheat. 40 is a draft of the gate and manner of hanging the elevator in it. See a particular description in the latter part of art. 95.

This gate is hung by a strong rope passing over a strong pulley or roller 41, and thence round the axis of the wheel 42; round the rim of which wheel there is a rope, which passes round the axis of wheel 43, round

the rim of which is a small rope, leading down over the pulley P, to the deck, and fastened to the cleet q; a man by pulling this rope can hoist the whole elevator; because if the diameter of the axis be 1 foot, and the wheel 4 feet, the power is increased 16 fold, by art. 20. The elevator is hoisted up, and rested against the wall, until the ship comes to, and is fastened steady in the right place, then it is set in the hold on the top of the wheat, and the bottom being open, the buckets fill as they pass under the pulley; a man holds by the cord, and lets the elevator settle as the wheat sinks in the hold, until the lower part of the case rests on the bottom of the hold, it being so long as to keep the buckets from touching the vessel; by this time it will have hoisted 1, 2, or 300 bushels, according to the size of the ship and depth of the hold, at the rate of 300 bushels per hour. When the grain ceases running in of itself, the man may shovel it up, till the load is discharged.

The elevator discharges the wheat into the conveyer at 44, which conveys it into the screen-hoppers 10—11, or into any other, from which it may descend into the elevator 4—5, or into the rubbing-stones 8.

This conveyer may serve instead of rubbing-stones, and the dust rubbed off thereby may be, by a wind-spout from the fan 13, into the conveyer at 45, blown out through the wall at p. The holes at 44 and 10—11 are to be small, to let but little wind escape any where but out through the wall, where it will carry the dust.

A small quantity of wind might be let into the conveyer 15—16, to blow away the dust rubbed off by it.

The fan must be made to blow very strong, to be sufficient for all these purposes, and the strength of the blast regulated as directed by art. 83.

ART. 91.

A MILL FOR GRINDING PARCELS.

Here each person's parcel is to be stored in a separate garner, and kept separate through the whole process of

manufacture, which occasions much labour; almost all of which is performed by the machines. See plate VI. fig. I; which is a view of one side of a mill containing a number of garners holding parcels, and a side view of the wheat elevator.

The grain is emptied into the garner g, from the wagon, as shewn in Plate VIII; and by drawing the gate A, it is let into the elevator AB, and elevated into the crane-spout B, which being turned into the mouth of the garner-spout BC, which leads over the top of a number of garners, and has, in its bottom, a little gate over each garner; which gates and garners are all numbered with the same numbers respectively.

Suppose we wish to deposit the grain in the garner No. 2, draw the gate 3 out of the bottom, and shut it in the spout, to stop the wheat from passing along the spout past the hole, so that it must all fall into the garner; and thus for the other garners 3-4-5-6, &c. These garners are all made like hoppers, about 4 inches wide at the floor, and nearly the length of the garner; but as it passes through the next story, it is brought to the form of a spout 4 inches square, leading down to the general spout KA, which leads to the elevator; in each of these spouts is a gate numbered with the number of its garner; so that when we want to grind the parcel in garner 2, we draw the gate 2 in the lower spout, to let the wheat run into the elevator at A, to be elevated into the crane-spout B, which is to be turned over the rolling-screen, as shewn in Plate VIII.

Under the upper tier of garners, there is another tier in the next story, set so that the spouts from the bottom of the upper tier pass down the partitions of the lower tier, and the upper spouts of the lower tier pass between the partitions of the upper tier, to the garner-spout.

These garners, and the gates leading both into and out of them, are numbered as the others.

If it is not convenient to fix the descending spouts BC, to convey the wheat from the elevator to the garners, and KA to convey it from the garners to the elevator again, then the conveyers r-s and I-K may be used for said purposes.

To keep the parcels separate, there should be a crane-spout to the meal elevator, or any other method, by which the meal of the second parcel may be guided to fall on another part of the floor, until the first parcel is all bolted, and the chests cleared out, when the meal of the second parcel may be guided into the hopper-boy.

I must here observe, that in mills for grinding parcels, the tail flour must be hoisted by a separate elevator to the hopper-boy, to be bolted over, and not run into the conveyer, as shewn in plate VIII; because then the parcels could not be kept separate.

The advantages of the machinery, applied to a mill for grinding parcels, are very great.

1. Because without them there is much labour in moving the different parcels from place to place, all which is done by the machinery.

2. The meal, as it is ground, is cooled by the machinery, in so short a time, and bolted, that when the grinding is done, the bolting is also nearly finished: Therefore,

3. It saves room, because the meal need not be spread over the floor to cool, there to lay 12 hours as usual, and none but one parcel need be on the floor at once.

4. It gives greater despatch, as the mill need never stop either stones or bolts, in order to keep parcels separate. The screenings of each parcel may be cleaned, as directed in art. 89, with very little trouble; and the flour may be nearly packed before the grinding is finished. So that if a parcel of 60 bushels arrive at the mill in the evening, the owner may wait till morning, when he may have it all finished; he may use the offal for feed for his team, and proceed with his load to market.

ART. 92.

A GRIST MILL FOR GRINDING VERY SMALL PARCELS.

Fig. 16, plate VII, is a representation of a grist-mill, so constructed that the grist being put into the hopper, it will be ground and bolted, and return into the bags again.

The grain is emptied into the hopper at A, and as it is ground it runs into the elevator at B, and is elevated and let run into the bolting hopper down a broad spout at C, and, as bolted, it falls into the bags at d. The chest is made to come to a point like a funnel, and a division made to separate the fine and coarse, if wanted, and a bag put under each part; on the top of this division is set a regulating board on a joint, as x, by which the fine and coarse can be regulated at pleasure.

If the bran requires to be ground over, (as it often does,) it is made to fall into a box over the hopper, and by drawing the little gate b, it may be let into the hopper as soon as the grain is all ground, and as it is bolted the second time, it is let run into the bag by shutting the gate b, and drawing the gate c.

If the grain is put into the hopper F, then as it is ground it falls into the drill, which draws it into the elevator at B, and it ascends as before.

To keep the different grists separate—When the miller sees the first grist fall into the elevator, he shuts the gate B or d, and gives time for it to get all into the bolting reel; he then stops the knocking of the shoe by pulling the shoe line, which hangs over the pullies pp, from the shoe to near his hand, making it fast to a peg; he then draws the gate B or d, and lets the second grist into the elevator, to fall into the shoe or bolting hopper, giving time for the first grist to be all into the bags, and the bags of the second grist put in their places; he then unhitches the line from the peg, and lets the shoe knock again, and begins to bolt the second grist.

If he does not choose to let the meal run immediately into the bags, he may have a box made with feet to stand in the place of the bags, for the meal to fall in, out of which it may be taken, and put into the bags, by the miller or the owner, as fast as it is bolted, and mixed as desired; and as soon as the first parcel is bolted, the little gates at the mouth of the bags may be shut, while the meal is filled out of the box, and the second grist may be bolting.

The advantages of this improvement on a grist-mill are,

1. It saves the labour of hoisting, spreading, and cooling the meal, and carrying up the bran to be ground over, sweeping the chest, and filling up the bags.

2. It does all with greater despatch, and less waste, without having to stop the stones or bolting-reel, to keep the grists separate, and the bolting is finished almost as soon as the grinding; therefore the owner will be the less time detained.

The chests and spouts should be made steep to prevent the meal from lodging in them, so that the miller, by striking the bottom of the chest, will shake out all the meal.

The elevator and drill should be so made as to clean out at one revolution. The drill might have a brush or two, instead of rakes, which would sweep the case clean at a revolution; and the shoe of the bolting hopper should be short and steep, so that it will clean out soon.

The same machinery may be used for merchant-work, by having a crane-spout at C, or a small gate, to turn the meal into the hopper-boy that tends the merchant bolt.

A mill thus constructed, might grind grists in the day-time, and merchant-work at night.

A drill is preferable to a conveyer for grist-mills, because they will clean out much sooner and better. The lower pulley of the elevator is twice as large in diameter as the pullies of the drill; the lower pulley of the elevator, and one pulley of the drill, are on the same shaft, close together, the elevator moves the drill, and the pulley of the drill being smallest, gives room for the meal to fall into the buckets of the elevator.

ART. 93.

OF ELEVATING GRAIN, SALT, OR ANY GRANULOUS SUBSTANCE, FROM SHIPS INTO STORE-HOUSES, BY THE STRENGTH OF A HORSE.

Plate VII, fig. 17, represents the elevator, and the manner of giving it motion; the horse is hitched to the end of the sweep-beam A, by which he turns the upright

shaft, on the top of which is the driving cog-wheel, of 96 cogs, $2\frac{1}{2}$ inches pitch, to gear into the leading wheel of 20 cogs, on the same shaft with which is another driving wheel of 40 cogs, to gear into another leading wheel of 19 cogs, which is on the same shaft with the elevator pulley; then if the horse makes about 3 revolutions in a minute (which he will do if he walk in a circle of 20 feet diameter) the elevator pulley will make about 30 revolutions in a minute; and if the pulley is 2 feet in diameter, and a bucket be put on every foot of the strap, to hold a quart each, the elevator will hoist about 187 quarts per minute, or 320 bushels in an hour, 3840 bushels in 12 hours; and for every foot the elevator is high, the horse will have to sustain the weight of a quart of wheat; say 48 feet, which is the height of the highest store-houses, then the horse would have to move $1\frac{1}{2}$ bushels of wheat upwards, with a velocity equal to his own walk; which I presume he can do with ease, and overcome the friction of the machinery: By which will appear the great advantages of this application.

The lower end of the elevator should stand near the side of the ship, and the grain, salt, &c. &c. be emptied into a hopper; the upper end may pass through a door or window, as may be most convenient; the lower case should be a little crooked to prevent the buckets from rubbing in their descent.

ART. 94.

OF AN ELEVATOR APPLIED TO ELEVATE GRAIN, &c. WROUGHT BY A MAN.

Plate VII, fig. 18, AB, are two ratchet wheels, with two deep grooves in each of them, for ropes to run in; they are fixed close together, on the same shaft with the upper pulley of the elevator, so that they will turn easily on the shaft the backward way, but a click falls into the ratchet, and prevents them from turning forwards. Fig. 19, is a side view of the wheel, ratchet, and click. C D are two

levers, like weavers' treadles, and from lever C there is a light staff passes to the foreside of the groove wheel B, and made fast by a rope half way round the wheel; and from said lever C there is a rope passing to the backside of the wheel A; and from lever D there is a light staff passing to the foreside of the groove wheel A, and a rope to the backside of the groove wheel B.

The man, who is to work this machine, stands on the treadles, and holds by the staffs with his hands: and as he treads on D it descends, and the staff pulls forward the wheel A, and the rope pulls backwards the wheel B, and as he treads on C the staff pulls forward the wheel B, and the rope pulls backward the wheel A: but as the click falls into the ratchet, so that the wheels cannot move forward without turning the elevator pulley, thus it is moved one way by the treadles; and in order to keep up a regular motion, F is a heavy fly-wheel, which should be of cast metal, to prevent much obstruction from the air.

To calculate what quantity a man can raise to any height, let us suppose his weight to be 150lbs. which is the power to be applied, and suppose he is able to walk about 70 feet up stairs in a minute, by the strength of both his legs and arms, or which is the same thing, to move his weight on the treadles 70 steps in a minute; then suppose we allow, as by art. 29—42, to lose 1-3 of the power to gain velocity and overcome friction, (which will be a great plenty in this case, because in the experiment in the table in art. 37, when 7lbs. were charged with 6lbs. they moved with a velocity of 2 feet in half a second,) then there will remain 100lbs. raised 70 feet in a minute, equal to 200lbs. raised 35 feet to the top of the third story per minute, equal to 200 bushels per hour, 2400 bushels in 12 hours.

The great advantages of this application of the elevator, and of this mode of applying man's strength, will appear from these considerations, viz. he uses the strength of both his legs and arms, to move his weight only, from one treadle to the other, which weight does the work; whereas, in carrying bags on his back, he uses the strength of his legs only, to raise both the

weight of his body and the burden, add to this that he generally takes a very circuitous route to the place where he is to empty the bag, and returns empty; whereas the elevator takes the shortest direction to the place of emptying, and is always steadily at work.

The man must sit on a high bench, as a weaver does, on which he can rest part of his weight, and rest himself occasionally, when the machine moves lightly, and have a beam above his head, that he may push his head against, to evercome extraordinary resistances. This is probably the best means of applying man's strength to produce rotary motions.

DESCRIPTION OF PLATE IX.

The grain is emptied into the spout A, by which it descends into the garner B; whence by drawing the gate at C, it passes into the elevator C D, which raises it to D, and empties it into the crane spout E, which is so fixed on gudgeons that it may be turned to any surrounding granaries, into the screen-hopper F, for instance, (which has two parts F and G,) out of which it is let into the rolling screen, at H, by drawing the small gate a. It passes through the fan I, and falls into the little sliding-hopper K, which may be moved, so as to guide it into either of the hanging-garners, over the stones, L or M, and it is let into the stone-hoppers by the little bags bb, as fast as it can be ground. When ground it falls into the conveyer N N, which carries it into the elevator at O O, this raises and empties it into the hopper-boy at P, which is so constructed as to carry it round in a ring, gathering it gradually towards the centre, till it sweeps into the bolting hoppers Q Q.

The tail flour, as it falls, is guided into the elevator, to ascend with the meal, and, that a proper quantity may be elevated, there is a regulating board R, set under the superfine cloths, on a joint x, so that it will turn towards the head or tail of the reel, and send more or less into the elevator, as may be required.

There may be a piece of coarse cloth or wire put on the tails of the superfine reels, that will let all pass through except the bran, which falls out at the tail, and

a part of which is guided into the elevator with the tail flour, to assist the bolting in warm weather; the quantity is regulated by a small board r, set on a joint under the ends of the reels. Beans may be used to keep the cloths open, and still be returned into the elevator to ascend again. What passes through the coarse cloth or wire, and the remainder of the bran, are guided into the reel S, to be bolted.

To clean Wheat several Times.

Suppose the grain to be in the screen hopper E. Draw the gate a; shut the gate e; move the sliding hopper K over the spout K c d; and let it run into the elevator to be raised again. Turn the crane spout over the empty hopper G, and the wheat will be all deposited there nearly as soon as it is out of the hopper F. Then draw the gate e, shut the gate a, and turn the crane spout over F; and so on alternately, as often as necessary. When the grain is sufficiently cleaned, slide the hopper K over the hole that leads into the stones.

The screenings fall into a garner, hopperwise, to clean them draw the gate f, and let them run into the elevator, to be elevated into the screen hopper F. Then proceed with them as with the wheat, till sufficiently clean. To clean the fannings, draw the little gate h, and let them into the elevator, &c. as before.

Fig. II. is a perspective view of the conveyer, as it lies in its troughs, at work; and shows the manner in which it is joined to the pullies, at each side of the elevator.

Fig. III. exhibits a view of the pulley of the meal elevator, as it is supported on each side, with the strap and buckets descending to be filled.

Fig. IV. is a perspective view of the underside of the arms of the hopper-boy, with flights complete. The dotted lines show the track of the flights of one arm; those of the other following, and tracking between them. A A are the sweepers. These carry the meal round in a ring, trailing it regularly all the way, the flights drawing it to the centre, as already mentioned. B B are the sweepers that drive it into the bolting hoppers.

Fig. V. is a perspective view of the bucket of the wheat-elevator; and shows the manner in which it is fastened, by a broad piece of leather, which passes through and under the elevator-strap, and is nailed to the sides with little tacks.

CHAPTER III.

OF THE CONSTRUCTION OF THE SEVERAL MACHINES.

ART. 95.

OF THE WHEAT ELEVATOR.

FIRST determine how many bushels it should hoist in an hour, and where it shall be set, so as to answer all the following purposes, if possible.

1. To elevate the grain from a wagon or ship.
2. From the different garners into which it may be stored.
3. If it be a two story mill, to hoist the wheat from the tail of the fan, as it is cleaned, to a garner over the stones.
4. To hoist the screenings to clean them several times.
5. To hoist the wheat from a shelling-mill, if there be one.

One elevator may do all this in a mill rightly planned, and most of it can be done in mills ready built.

Then if you wish it to hoist about 300 bushels in an hour, make the strap $4\frac{1}{2}$ inches wide, of good, strong, white harness-leather, only one thickness. It must be cut and joined together in a straight line, with the thickest and consequently the thinnest ends together, so that if they be too thin they may be lapped over and doubled, until they are thick enough singly. Then, to make wooden buckets, take the butt of a willow or water-birch, that will split freely, cut it in bolts 15 inches long, and rive and shave it into staves $5\frac{1}{2}$ inches wide, and three-eighths of an inch thick; these will make one bucket each. Set a pair of compasses to the width of the strap, and make the sides and middle of the bucket equal thereto at the mouth, but let the sides be only two-

thirds of that width at the bottom, which will make it of the form of fig. 9, plate 6; the ends being cut a little circular, to make the buckets lay closer to the strap and wheel. As it passes over, make a pattern of the form of fig. 9, to describe all the rest by. This makes a bucket of a neat form, to hold about 75 solid inches, or somewhat more than a quart. Then to make them bend to a square at the corners e c, cut a mitre square across where they are to bend, about 2-8 through; boil them and bend them hot, taking a strip of leather across them, to hold them in that form until they get cold, and then put bottoms to them of the thin skirts of the harness leather. These bottoms are to extend from the lower end to the strap that binds it on. Then, to fasten them on well and with despatch, prepare a number of straps $1\frac{3}{4}$ inches wide, of the best cuttings of the harness leather, wet them and stretch them as hard as possible, which reduces their width to about $1\frac{1}{2}$ inches. Nail one of these straps to the side of a bucket, with 5 or 6 strong tacks that will reach through the bucket and clinch inside. Then take a $1\frac{1}{2}$ inch chisel, and strike it through the main strap about a quarter of an inch from each edge, and put one end of the binding-strap through the slits, draw the bucket very closely to the strap, and nail it on the other side of the bucket, which will finish it. See B in fig. 2, plate 6. C is a meal-bucket fastened in the same manner, but is bottomed only with leather at the lower end, the main strap making the bottom side of it. This is the best way I have yet discovered to make wooden buckets. The scraps of the harness leather, out of which the elevator-straps are cut, are generally about enough to complete the buckets, which works it all up.

To make Sheet-Iron Buckets.

Cut the sheet in the form of fig. 8, plate VI. making the middle part c, and the sides a and b nearly equal to the width of the strap, and nearly $5\frac{1}{2}$ inches long, as before. Bend them to a right angle at every dotted line, and the bucket wiil be formed. c will be the bottom side next to the strap; and the little holes a a and b b will meet, and must be rivetted to hold it together. The two

holes c are for fastening it to the straps by rivets. The part a b is the part that dips up the wheat, and the point being doubled back strengthens it, and tends to make it wear well. The bucket being completely formed, and the rivet-holes made, spread one out again, as fig. 8, to describe all the rest by, and to mark for the holes, which will meet again when folded up. They are fastened to the strap by two rivets with thin heads put inside the bucket, and a double burr of sheet iron put on the under side of the strap, which fastens them on very tightly. See A, plate VI, fig. 2. These buckets will hold about 1,3 quarts, or 88 cubic inches. This is the best way I have found to make sheet-iron buckets. D is a meal-bucket of sheet-iron, rivetted on by two rivets, with their heads inside the strap; the sides of the buckets are turned a little out, and holes made in them for the rivets to pass through. Fig. 11 is the form of one spread out, and the dotted lines show where they are bent to right angles to form them. The strap forms the bottom side of these buckets.

Make the pulleys 24 inches diameter, as thick as the strap is wide, and half an inch higher in the middle than at the sides, to make the strap keep on; give them a motion of 25 revolutions in a minute, and put on a sheet-iron bucket for every 15 inches; then 125 buckets will pass per minute, which will carry 162 quarts, and hoist 300 bushels in an hour, and 3600 bushels in 12 hours. If you wish to hoist faster, make the strap wider, the buckets larger in proportion, and increase the velocity of the pulley, but not above 35 revolutions in a minute, nor more buckets than one for every 12 inches, otherwise they will not empty well. A strap of 5 inches, with buckets 6 inches long, and of a width and proportion suiting the strap ($4\frac{1}{2}$ inches wide) will hold 1,8 quarts each; and 35 revolutions of the pulley will pass 175 buckets, which will carry 315 quarts in a minute, and 590 bushels in an hour. If the strap be 4 inches wide, and the wooden buckets 5 inches deep, and in proportion to the strap, they will hold ,8 of a quart: then, if there be one for every 15 inches, and the pulley revolves 27 revolutions in a minute, it will hoist 200 bushels in an hour, where there is a good garner to empty the

wheat into. This is sufficient for unloading wagons, and the size they are commonly made.

Plate VI, fig. 6, represents the gudgeon of the lower pulley; fig. 7, the gudgeon for the shaft on which the upper pulley is fixed. Fix both the pulleys in their places, but not firmly, so that a line stretched from one pulley to the other, will cross the shafts or gudgeons at right angles. This must always be the case to make the straps work fairly. Put on the strap with the buckets; draw it tightly and buckle it; put it in motion, and if it does not keep fairly on the pulleys, their position may be altered a little. Observe how much the descending strap swags by the weight of the buckets, and make the case round it so crooked, that the points of the buckets will not rub in their descent, which will cause them to wear much longer and work easier. The side boards need not be made crooked in dressing out, but may be bent sufficiently by sawing them half way or two-thirds through, beginning at the upper edge, holding the saw very much aslant, the point downwards and inwards, so that in bending the parts will slip past each other. The upper case must be nearly straight; for if it be made much crooked, the buckets will incline to turn under the strap. Make the cases 3-4 of an inch wider than the strap and buckets inside, and $1\frac{1}{2}$ inch deeper, that they may play freely; but do not give them room to turn upside down. If the strap and buckets be 4 inches, then make the side boards $5\frac{1}{2}$, and the top and bottom boards $6\frac{3}{4}$ inches wide, of inch boards. Be careful that no shoulders nor nail-points be left inside of the cases, for the buckets to catch in. Make the ends of each case, where the buckets enter as they pass over the pulleys, a little wider than the rest of the case. Both the pulleys are to be nicely cased round to prevent waste, not leaving room for a grain to escape, continuing the case of the same width round the top of the upper, and bottom of the lower pulley; then if any of the buckets should ever get loose, and stand askew, they will be kept right by the case; whereas, if there were any ends of boards or shoulders, they would catch against them. See A B, plate VI, fig. 1. The bottom of the case of the upper

pulley must be descending, so that what grain may be falling out of the buckets in passing over the pulleys, may be guided into the descending case. The shaft passing through this pulley is made round where the case fits to it: half circles are cut out of two boards, so that they meet and embrace it closely. The undermost board, where it meets the shaft, is ciphered off inside next the pulley, to guide the grain inward. But it is full as good a way to have a strong gudgeon to pass through the upper pulley, with a tenon at one end, to enter a socket, which may be in the shaft, that is to give it motion. This will best suit where the shaft is short, and has to be moved to put the elevator out, and in gear.

The way that I have generally cased the pulleys is as follows, viz. The top board of the upper strap-case, and the bottom board of the lower strap-case are extended past the lower pulley to rest on the floor; and the lower ends of these boards are made two inches narrower, as far as the pulley-case extends; the side board of the pulley is nailed, or rather screwed, to them with wood screws. The rest of the case boards join to the top of the pulley-case, both being of one width. The block which the gudgeons of this pulley run in, are screwed fast to the outside of the case boards; the gudgeons do not pass quite through, but reach to the bottom of the hole, which keeps the pulley in its place.

The said top and bottom boards, and also the side boards of the strap-cases, are extended past the upper pulley, and the side boards of the pulley-case are screwed to them; but this leaves a vacancy between the top of the side boards of the strap-cases, and shoulders for the buckets to catch against. This vacancy is to be filled up by a short board, guiding the buckets safely over the upper pulley. The case must be as close to the points of the buckets, where they empty, as is safe, that as little as possible may fall down again. There is to be a long hole cut into the case at B, for the wheat to fall out at, and a short spout guiding it into the crane spout. The top of the short spout next B, should be loosely fastened in with a button, that it may be taken off, to

examine if the buckets empty well, &c. Some neat workmen have a much better way of casing the pulleys, that I cannot here describe; what I have described is the cheapest, and does very well.

The wheat should be let in at the bottom, to meet the buckets, and a gate to shut as near the point of them as possible, as at A, plate VI, fig. 1. Then if the gate be drawn sufficiently to fill the buckets, and the elevator be stopped, the wheat will stop running in, and the elevator will be free to start again; but if it had been let in any distance up, then, when the elevator stopped, it would fill from the gate to the bottom of the pulley, and the elevator could not start again. If it be in any case let in any distance up, the gate should be so fixed, that it cannot be drawn so far, as to let in the wheat faster than the buckets can take it, else the case will fill and stop the buckets. If it be let in faster at the hindmost side of the pulley, than the buckets will carry it, the same evil will occur; because the buckets will push the wheat before them, being more than they can hold, and give room for too much to come in; therefore there should be a relief gate at the bottom to let the wheat out, if ever there happens to get too much in.

The motion is to be given to the upper pulley of all elevators, if it can be done, because the weight in the buckets, causes the strap to hang tighter on the upper, and slacker on the lower pulley; therefore the upper pulley will carry the greatest quantity without slipping. All elevators should stand a little slanting, because they will discharge the better. The boards for the cases should be of any unequal lengths, so that two joints will never come close together, which makes the case strong. Some have joined the cases at every floor, which is a great error. There must be a door in the ascending case, at the most convenient place, to buckle the strap, &c. &c.

Of the Crane Spout.

To make a crane spout, fix a board 18 or 20 inches broad truly horizontal, or level, as a under B, in plate VI, fig. 1. Through the middle of this board the wheat

is conveyed, by a short spout from the elevator. Then make the spout of 4 boards, 12 inches wide at the upper, and about 4 or 5 inches at the lower end. Cut the upper end off aslant, so as to fit nicely to the bottom of the board; hang it to a strong pin, passing through the broad board near the hole through which the wheat passes, so that the spout may be turned in any direction and still cover the whole, at the same time it is receiving the wheat, and guiding it into any garner, at pleasure. In order that the pin may have a strong hold of the board and spout, there must be a piece of scantling, 4 inches thick, nailed on the top of the board, for the pin to pass through; and another to the bottom, for the head of the pin to rest on. But if the spout be long and heavy, it is best to hang it on a shaft, that may extend down to the floor, or below the collar-beams, with a pin through it, as x, to turn the spout by. In crane spouts for meal it is sometimes best to let the lower board reach to, and rest on the floor. If the elevator-cases and crane-spout be well fixed, there can neither grain nor meal escape or be wasted that enters the elevator, until it comes out at the end of the crane-spout again.

*Of an Elevator to elevate Wheat from a Ship's Hold.**

Make the elevator complete (as it appears 35—39, plate 8) on the ground (and raise it afterwards.) The pulleys are to be both fixed in their places and cased; and the blocks that the gudgeon of the upper pulley is to run in, are to be rivetted fast to the case-boards of the pulley, and these case-boards screwed to the strap-cases by long screws, reaching through the case-boards edgeways. Both sides of the pulley-case are fastened by one set of screws. On the outside of these blocks, round the centre of the gudgeons, are circular knobs, 6 inches diameter, and 3 inches long, strongly rivetted to keep them from splitting off, because by these knobs the whole weight of the elevator is to hang. In the moveable frame 40. oo, oo, are these blocks with their knobs, let into the pieces of the frame B C rs. The gudgeons

* See the description of this elevator in art. 90.

of the upper pulley p pass through these knobs, and play in them. Their use is to bear the weight of the elevator that hangs by them; the gudgeons, by this means, bear only the weight of the strap and its load, as is the case with other elevators. Their being circular gives the elevator liberty to swing out from the wall to the hold of the ship.

The frame 40 is made as follows: the top piece A B is 9 by 8, strongly tenoned into the side pieces A D and B C with double tenons, which side pieces are 8 by 6. The piece r s is put in with a tenon, 3 inches thick, which is dovetailed, keyed, and drawpinned, with an iron pin, so that it can easily be taken out. In each side piece A D and B C there is a row of cogs, set in a circle, that are to play in circular rabbets in the posts p. 41. These circles are to be described with a radius, whose length is from the centre of the joint gudgeons G, to the centre of the pulley 39; and the posts must be set up, so that the centre of the circle, will be the centre of the gudgeon G; then the gears will be always right, although the elevator rise and fall to suit the ship or tide. The top of those circular rabbets ought to be so fixed, that the lower end of the elevator may hang near the wall. This may be regulated by fixing the centre of gudgeon G. The length of these rabbets is regulated by the distance the vessel is to rise and fall, to allow the elevator to swing clear of the vessel light at high water. The best way to make the circular rabbets is, to dress two pieces of 2 inch plank for each rabbet, of the right circle, and pin them to the posts, at such a distance, leaving the rabbet between them.

When the gate and elevator are completed, and tried together; the gate hung in its rabbets, and played up and down, then the elevator may be raised by the same power; that is, to raise and lower it as described, art. 4.

ART. 96.

OF THE MEAL-ELEVATOR.

Little may be said of the manner of constructing the meal-elevator, after what has been said in art. 90, except

giving the dimensions. Make the pulleys $3\frac{1}{2}$ inches thick, and 18 inches diameter. Give them no more than 20 revolutions in a minute. Make the strap $3\frac{1}{2}$ inches wide, of good, pliant, white harness-leather; make buckets either of wood or sheet-iron, to hold about half a pint each; put one for every foot of the strap; make the cases tight, especially round the upper pulley, slanting much at bottom, so that the meal which falls out of the buckets, may be guided into the descending case. Let it lean a little, that it may discharge the better. The spout that conveys the meal from the elevator to the hopper-boy, should not have much more than 45 degrees descent, that the meal may run easily down, and not cause a dust; fix it so that the meal will spread thinly over its bottom; in its descent it will cool the better. Cover the top of the spout half-way down, and hang a thin, light cloth at the end of this cover, to check all the dust that may raise, by the fall of the meal from the buckets. Remember to take a large cipher off the inside of the board, where it fits to the undermost side of the shaft of the upper pulley; else the meal will work out along the shaft. Make all tight, as directed, and it will effectually prevent waste.

In letting meal into an elevator, it must be let in some distance above the centre of the pulley, that it may fall clear from the spout that conveys it in; otherwise it will clog and choak. Plate VI. fig. 4, is the double socket gudgeon of the lower pulley, to which the conveyer joins. Fig. 3, a b c d, is a top view of the case that the pulley runs in, which is constructed thus; a b is a strong plank, 14 by 3 inches, steped in the sill, dovetailed and keyed in the meal-beam, and is called the main bearer. In this, at the determined height, is framed the gudgeon bearers a c b d, which are planks 15 by $1\frac{1}{2}$ inches, set $7\frac{1}{2}$ inches apart, the pulley running between, and resting on them. The end piece c d 7 inches wide and 2 thick, is set in the direction of the strap-case, and extends 5 inches above the top of the pulley; to this the bearers are nailed. On the top of the bearers, above the gudgeons, are set two other planks 13 by $1\frac{1}{2}$ inches, rabbetted into the main bearer, and screwed fast to the end piece c d: these

are 4 inches above the pulley. The bottom piece of this case slides in between the bearers, resting on two cleets, so that it can be drawn out to empty the case, if it should ever by any means be overcharged with meal; this completes the case. In the gudgeon bearer under the gudgeons are mortises, made about 12 by 2 inches, for the meal to pass from the conveyer into the elevator; the bottom board of the conveyer trough rests on the bearer in these mortises. The strap-case joins to the top of the pulley case, but is not made fast, but the back board of the descending case is steped into the inside of the top of the end piece c d. The bottom of the ascending case is to be supported steady to its place, and the board at the bottom must be ciphered off at the inside, with long and large ciphers, making them at the point only 1-4 inch thick; this is to make the bottom of the case wide for the buckets to enter, if any of them should be a little askew, because the pulley-case is wider than the strap-cases, to give room for the meal from the conveyer to fall into the buckets; and in order to keep the passage open, there is a piece 3 inches wide, and $1\frac{3}{4}$ inch thick, put on each side of the pulley to stand at right angles with each other, extending $3\frac{1}{2}$ inches at each end past the pulley, and are ciphered off, so as to clear the strap, and draw the meal under the buckets; these are called bangers.

ART. 97.

OF THE MEAL-CONVEYER.

See it described, art. 88. Plate VI, fig. 3, is a conveyer joined to the pulley of the elevator. Fig. 4 is the gudgeon that is put through the lower pulley, to which the conveyer is joined by a socket, as represented. Fig. 5 is a view of the said socket and the band, as it appears on the end of the shaft. The tenon of the gudgeon is square, that the socket may fit it every way alike. Make the shaft $5\frac{1}{2}$ inches diameter, of eight equal sides, and put on the socket and the gudgeon; then, to lay it out for the flights,

begin at the pulley, mark as near the end as possible, on the one side, and turning the shaft the way it is to work, at the distance of 1½ inch towards the other end, set a flight on the next side, and thus go on to mark for a flight on every side, still advancing 1½ inch to the other end, which will form the dotted spiral line, which would drive the meal the wrong way; but the flights are to be set across this spiral line, at an angle of about 30 degrees, with a line square across the shaft; and then they will drive the meal the right way, the flights operating like ploughs.

To make the flights, take good maple, or other smooth hard wood; saw it in 6 inch lengths; split it always from the sap to the heart; make pieces 2½ inches wide, and 3-4 of an inch thick; plane them smooth on one side, and make a pattern to describe them by, and make a tenon 2½ inches long, to suit a 3-4 inch auger. When they are perfectly dry, having the shaft bored, and the inclination of the flights marked by a scribe, drive them in and cut them off 2½ inches from the shaft, dress them with their foremost edge sharp, taking all off from the back side, leaving the face smooth and straight, to push forward the meal; make their ends nearly circular. If the conveyer be short, put in lifting flights, with their broad side foremost, half the number of the others, between the spires of them; they cool the meal by lifting and letting it fall over the shaft.

To make the trough for it to run in, take 3 boards, the bottom one 11, back 15, and front 13 inches. Fix the block for the gudgeon to run in at one end, and fill the comers with cleets, to make the bottom nearly circular, that but little meal may lay in it; join it neatly to the pulley-case, resting the bottom on the bottom of the hole cut for the meal to enter, and the other end on a supporter, that it can be removed and put to its place again with ease, without stopping the elevator.

A meal-elevator and conveyer thus made, of good materials, will last 50 years, with very little repair, and save more meal from waste, than will pay for building and repairing them for ever. The top of the trough must be left open, to let the stream of the meal out:

and a door may be made in the ascending case of the elevator, about 4 feet long, to buckle the strap tighter, &c. The strap of the elevator turns the conveyer, so that it will be easily stopped if any thing should be caught in it, being dangerous to turn it by cogs. This machine is often applied to cool the meal, without the hopper-boy, and attend the bolting-hopper, by extending it to a great length, and conveying the meal immediately into the hopper, which does very well, and some prefer it; but a hopper-boy is preferable where there is room for one.

ART. 98.

OF A GRAIN-CONVEYER.

This machine has been constructed in a variety of ways, the best I take to be as follows, viz. Make a round shaft, 9 inches diameter. Then, to make the spire, take strong sheet-iron, make a pattern 3 inches broad and of the true arch of a circle; the diameter of which (being the inside of the pattern) is to be 12 inches; this will give it room to stretch along a 9 inch shaft, so as to make a hasty spire, that will advance about 21 inches along the shaft every revolution. By this pattern cut the sheet-iron into circular pieces, and join the ends together by rivetting and lapping them, so as to let the grain run freely over the joints; when they are joined together they will form several circles, one above the other, slip it on the shaft, and stretch it along as far as you can, till it comes tight to the shaft, and fasten it to its place by pins, set in the shaft at the back side of the spire, and nail it to the pins: it will now form a beautiful spire 21 inches apart, which is too great a distance; therefore there should be two or three of these spires made, and wound into each other, and all be put on together, because if one be put on first, the others cannot be got on so well afterwards; they will then be 7 inches apart, and will convey wheat very fast. If these spires be punched full of holes like a grater, and the

trough lined with sheet-iron punched full of small holes, it will be an excellent rubber; will clean the wheat of the dust and down, that adheres to it, and supersede the necessity of any other rubbing-machine.

The spires may also be formed with either wooden or iron flights, set so near to each other in the spiral lines, as to convey the wheat from one to another.

ART. 99.

OF THE HOPPER-BOY.

This machine has appeared in various constructions, the best of which is represented by Plate VII. fig. 12: see the description, art. 88.

To make the flight-arms C D, take a piece of dry poplar, or other soft scantling 14 feet long, 8 by $2\frac{1}{2}$ inches in the middle, 5 by $1\frac{1}{2}$ inches at the end, and straight at the bottom; on this strike the middle line a b, fig. 13. Consider which way it is to revolve, and cipher off the under side of the foremost edge from the middle line, leaving the edge 3-4 of an inch thick, as appears by the shaded part. Then to lay out the flights, take the following

RULE.

Set your compasses at $4\frac{1}{2}$ distance, and, beginning with one foot in the centre c, step towards the end b, observing to lessen the distance one sixteenth part of an inch every step; this will set the flights closer together at the end than at the centre. Then to set the flights of one arm to track truly between those of the other, and to find their inclination, with one point in the centre c, sweep the dotted circles across every point in one arm, then, without altering the centre or distance, make the little dotted marks on the other arm, and between them the circles are to be swept for the flights in it. Then, to vary their inclination, regularly from the end to the centre, strike the dotted line c d half an inch from the centre c, and $2\frac{1}{2}$ inches from the middle line at d. Then with the compasses set to half an inch, set off the incli-

nation from the dotted circles on the line c d. Then, because the line c d approaches the middle line, the inclination is greater near the centre than at the end, and vary regularly. Dovetail the flights into the arm, observing to put the side that is to drive the meal to the line of inclination. The bottoms of them should not extend past the middle line, the ends being all rounded and dressed off at the back side to make the point sharp, leaving the driving side quite straight like the flight r. See them complete in the end c a. The sweepers should be 5 or 6 inches long, screwed on behind the flights, at the back side of the arms, one at each end of the arm, and one at the part that passes over the hopper: their use is described art. 88.

The upright shaft should be 4 by 4 inches, and made round for about 4½ feet at the lower end, to pass lightly through the centre of the arm. To keep the arm steady, there is a stay-iron 15 inches high, its legs 1-2 inch by 3-4, to stride 2 feet. The ring at the top should fit the shaft neatly, and be smooth and rounded inside, that it may slide easily up and down; by this the arm hangs to the rope that passes over a pulley at the top of the shaft 8 inches diameter, with a deep groove for the rope or cord to run in. Make the leading arm 6 by 1¼ inches in the middle, 2 by 1 inch at the end, and 8 feet long. This arm must be braced to the cog-wheel above, to keep it from splitting the shaft by any extra stress.

The weight of the balance w must be so near equal to the weight of the arm, that when it is raised to the top it will descend quietly.

In the bottom of the upright shaft is the step-gudgeon (fig. 15,) which passes through the square plate 4 by 4 inches, (fig. 14,) on this plate the arm rests, before the flights touch the floor. The ring on the lower end of the shaft is less than the shaft, that it may pass through the arm: this gudgeon comes out every time the shaft is taken out of the arm.

If the machine is to attend but one bolting-hopper, it need not be above 12 or 13 feet long. Set the upright shaft close to the hopper, and the flights all gather as the end c b, fig. 13. But if it is to attend for the grinding

of two pair of stones, and two hoppers, make it 15 feet long, and set it between them a little to one side of both, so that the two ends may not both be over the hoppers at the same time, which would make it run unsteady; then the flights between the hoppers and the centre must drive the meal outwards to the sweepers, as the end c a, fig. 13.

If it is to attend two hoppers, and cannot be set between them for want of room, then set the shaft near to one of them; make the flights that they all gather to the centre, and put sweepers over the outer hopper, which will be first supplied, and the surplus carried to the other. The machine will regulate itself to attend both, although one should feed three times as fast as the other.

If it be to attend three hoppers, set the shaft near the middle one, and put sweepers to fill the other two, the surplus will come to the centre one, and it will regulate to feed all three; but should the centre hopper ever stand while the others are going (of either of these last applications), the flights next the centre must be moveable that they may be turned, and set to drive the meal out from the centre; hopper-boys should be moved by a strap in some part of their movement, that they may easily stop if any thing catch in them; but several ingenious mill-wrights do prefer cogs; they should not revolve more than 4 times in a minute.

This machine may be made of a great many different forms and constructions on the same principles, to answer the same end, in a lesser degree of perfection.

ART. 100.

OF THE DRILL.

See the description, art. 1. The pulleys should not be less than 10 inches diameter for meal, and more for wheat. The case they run in is a deep narrow trough, say 16 inches deep, 4 wide, pulleys and strap 3 inches. The rakes are little square blocks of willow or poplar,

or any soft wood, that will not split with the nails, all of one size that each may take an equal quantity, nailed to the strap with long, small nails, with broad heads, which are inside the strap; the meal should be let into them always above the centre of the pulley, or at the top of it, to prevent its choaking, which it is apt to do, if let in low. The motion should be slow for meal; but may be more lively for wheat.

Directions for using a Hopper-boy.

1. When the meal-elevator is set in motion to elevate the meal; the hopper-boy must be set in motion also, to spread and cool it; and as soon as the circle is full, the bolts may be started; the grinding and bolting may likewise be carried on together regularly, which is the best way of working.

2. But if you do not choose to bolt as you grind, turn up the feeding sweepers and let the hopper-boy spread and cool the meal, and rise over it; and when you begin to bolt turn them down again.

3. If you choose to keep the warm meal separate from the cool, shovel about 18 inches of the outside of the circle in towards the centre, and turn the end flights, to drive the meal outwards; it will spread the warm meal outwards, and gather the cool meal in the bolting-hopper. As soon as the ring is full with warm meal, rake it out of the reach of the hopper-boy, and let it fill again.

4. To mix tail-flower or bran, &c. with a quantity of meal that is under the hopper-boy, make a hole for it in the meal quite to the floor, and put it in; and the hopper-boy will mix it regularly with the whole.

5. If it does not keep the hopper full, turn the feeding sweeper a little lower, and throw a little meal on the top of the arm, to make it sink deeper into the meal. If the spreading sweepers discharge their loads too soon, and do not trail the meal all around the circle, turn them a little lower; if they do not discharge, but keep too full, raise them a little.

CHAPTER IV.

ART. 101.

OF THE UTILITY OF THESE INVENTIONS AND IMPROVEMENTS.

DR. WISTAR, of Philadelphia, has discovered and proved by many experiments, (which he communicated to the American Philosophical Society, and which they have published in the 3d volume of their Transactions,) that cold is one principal agent in causing moisture to evaporate from bodies; and the fact is evident from daily observation, viz. that it is the different degrees of heat and cold, between the air and bodies, that causes them to cast off or contract moisture.

1st. We see in all sudden transitions from an extreme cold air to a warm, that the walls of houses, stones, ground, and every thing that retains cold, contracts moisture; and it certainly has the same effect on meal.

2. In all sudden changes from warm to cold, every thing casts off its moisture; for instance, what great quantities of water will disappear from the ground, in one cold night; this is the reason why meal being warm gets so dry in cold weather, and bolts so free; whereas it is always harder to bolt when there is a change from cold to warm.

3. If you warm a razor, or a glass, warmer than your breath, neither of them will be sullied by it.

4. Fill a glass bottle with cold water in a warm day, and wipe it dry, and there will be presently seen on its outside large drops, collected from the moisture of the air, though the bottle still continues full.

From these instances, it is evident, that the meal should be spread as thin as possible, and be kept in motion from the moment it leaves the stones, until it is cold, that it may have a fair opportunity of casting off its moisture, which will be done more effectually in that time, than can possibly be effected in warm weather, in

any reasonable time, after it has grown cold in a heap and retained its moisture; and there is no time for insects to deposit their eggs, that may in time breed the worms, that are often found in the heart of barrels of flour well packed, and by the moisture being cast out more effectually, it will not be so apt to sour. Therefore one great advantage is, that *the meal is better prepared for bolting, packing, and keeping, in much less time.*

2. *They do the work to much greater perfection*, by cleaning the grain and screenings more effectually, hoisting and bolting over great part of the flour, and grinding and bolting over the middlings, all at one operation, mixing those parts that are to be mixed, and separating such as are to be separated, more effectually.

3. *They save much meal from being wasted*, if they be well constructed, because there is no necessity of trampling in it, which trails it wherever we walk, nor shoveling it about to raise a dust that flies away, &c. This article of saving will soon pay the first cost of building, and keep them in repair afterwards.

4. *They afford more room than they take up*, because the whole of the meal-loft that heretofore was little enough to cool the meal on, may now be spared for other uses, except the circle described by the hopper-boy; and the wheat garners may be filled from one story to another, up to the crane spout, above the collar-beams; so that a small part of the house will hold a quantity of wheat, and it may be drawn from the bottom into the elevator as wanted.

5. *They tend to dispatch business*, by finishing as they go; so that there is not as much time expended in grinding over middlings, which will not employ the power of the mill, nor in cleaning and grinding the screenings, they being cleaned every few days, and mixed with the wheat; and as the labour is easier, the miller can keep the stones in better order, and more regularly and steady at work, especially in the night time, when they frequently stop for want of help, whereas one man, would be sufficient to attend six pair of stones running (in one house) well attended by machinery.

6. *They last a long time with but little expense of repair*, because their motions are slow and easy.

7. *They hoist the grain and meal with less power, and disturb the motion of the mill much less than the old way*, because the descending strap balances the ascending one, so that there is no more power used, than to hoist the grain or meal itself; whereas in the old way for every 3 bushels of wheat, which fills a 4 bushel tub with meal, the tub has to be hoisted, the weight of which is equal to a bushel of wheat, consequently the power used, is as 3 for the elevator to 4 for the tubs, which is one fourth less with elevators than tubs; besides the weight of 4 bushels of wheat, thrown at once on the wheel, always checks the motion, before the tub is up; the stone sinks a little, and the mill is put out of tune every tubfull, which makes a great difference in a year's grinding; this is worthy of notice when the water is scarce.

8. *They save a great expense of attendance.* One half of the hands that were formerly required are now sufficient, and their labour is easier. Formerly one hand was required for every 10 barrels of flour that the mill made daily; now one for every 20 barrels is sufficient. A mill that made 40 barrels a day, required four men and a boy; two men are now sufficient.

Two mens' wages, at 7 dolls. each, per month,	168 dolls.
Boarding &c. for do. at 15*l.* per year, -	80
One boy's board, clothing, &c. - -	50
	298

There appears a saving of 298 dollars a year, in the article of wages and board, in one double mill.

In support of what is here said, I add the following certificates.

I.

WE do certify, that we have erected *Oliver Evans's* new invented mode of elevating, conveying, and cooling meal, &c. As far as we have experienced, we have found them to answer a valuable purpose, well worthy the attention of any person concerned in merchant, or

even extensive country mills, who wishes to lessen the labour and expense of manufacturing wheat into flour.

JOHN ELLICOTT,
JONATHAN ELLICOTT,
GEORGE ELLICOTT,
NATHANIEL ELLICOTT.

Ellicott's mills, Baltimore county, state of Maryland, August 4, 1790.

II.

WE, the subscribers, do hereby certify, that we have introduced *Oliver Evans's* improvements into our mills at Brandywine, and have found them to answer, as represented to us by a plate and description; also to be a great saving of waste, labour and expense, and not subject to get out of order. We therefore recommend them as well worthy the attention of those concerned in manufacturing grain into flour.

JOSEPH TATNALL,
THOMAS LEA,
SAMUEL HOLLINGSWORTH,
THOMAS SHALLCROSS,
CYRUS NEWLIN.

Brandywine mills, 3d month 28th, 1791.

III.

WE do certify, that we have used *Oliver Evans's* machinery for the space of two years, in our mills, at Petersburg, in Virginia, consisting of three water-wheels, and three pair of stones; and we judge that they have been, and will continue to be, a saving of 300 dollars per year.

N. ELLICOTT & Co.

February 20, 1794.

IV.

WE do certify, that we have used *Oliver Evans's* patent machinery in our mills at Manchester, in the state of Virginia, consisting of three water-wheels, and three pair of stones, for the space of one year, and we judge upon fair calculations that they are a saving to us of 300 dollars per annum.

NICHOLSON & TAYLOR.

Many more to the same purpose might be added, but these may suffice.

Supposing the reader is now fully convinced of the utility of these improvements, I proceed to give the following bills of materials.

CHAPTER V.

BILLS OF MATERIALS TO BE PROVIDED FOR BUILDING AND CONSTRUCTING THE MACHINERY.

ART. 102.

For a Wheat-Elevator 43 *feet high, with a Strap* 4 *inches wide.*

Three sides of good, firm, white harness-leather.

220 feet of inch pine, or other boards that are dry, of about 12½ inches wide, for the cases; these are to be dressed as follows:

86 feet in length, 7 inches wide, for the top and bottom.

86 feet in length, 5 inches wide, with the edges truly squared, for the side boards.

A quantity of inch boards for the garners, as they may be wanted.

Sheet-iron or a good butt of willow wood, for the buckets.

2000 tacks, 14 and 16 ounce size, the largest about half an inch long, for the buckets.

3lb of 8d. and 1lb. of 10d. nails, for the cases.

2 dozen of large wood screws (but nails will do) for pulley-cases.

16 feet of 2 inch plank for pulleys.

16 feet of ditto, for cog-wheels, and dry pine scantling 4½ by 4½, or 5 by 5 inches, to give it motion.

Smith's Bill of Iron.

1 double gudgeon 3-4 inch, (such as fig. 6, plate VI.) 5 inches between the shoulders, 3¾ inches between the holes, the necks, or gudgeon-part, 3 inches.

1 small gudgeon, of the common size, 3-4 inch thick.
1 gudgeon an inch thick, (fig. 7,) neck $3\frac{1}{4}$ tang. 10 inches, to be next the upper pulley.
2 small bands, $4\frac{1}{4}$ inches from the outsides.
1 harness-buckle, 4 inches from the outsides, with 2 tongues, of the form of fig. 12.
Add whatever more may be wanting for the gears, that are for giving it motion.

For a Meal-Elevator 43 Feet high, Strap $3\frac{1}{2}$ Inches wide, and a Conveyer for two pair of Stones.

270 feet of dry pine, or other inch boards, most of them $11\frac{1}{2}$ or 12 inches wide, of any length, that they may suit to be dressed for the case boards, as follows:
86 feet in length, $6\frac{1}{2}$ inches wide, for tops and bottoms of the cases.
86 feet in length, $4\frac{1}{2}$ inches wide, for the side boards, truly squared at the edges.
The back board of the conveyer trough 15 inches, bottom do. 11 inches, and front 13 inches wide.
Some 2 inch plank for the pulleys and cog-wheels.
Scantling for conveyers 6 by 6, or $5\frac{1}{2}$ by $5\frac{1}{2}$ inches, of dry pine or yellow poplar; (prefer light wood) pine for shafts, $4\frac{1}{2}$ by $4\frac{1}{2}$ or 5 by 5 inches.
$2\frac{1}{2}$ sides of good, pliant-harness-leather.
1500 of 14 ounce tacks.
A good, clean butt of willow for buckets, unless the pieces that are left, that are too small for the wheat-buckets, will make the meal-buckets.
4lb. of 8d. and 1lb. of 10d. nails.
2 dozen of large wood screws (nails will do) for the pulley-cases.

Smith's Bill of Iron.

1 double gudgeon, (such as fig. 4, Plate VI,) $1\frac{1}{2}$ inch thick, $7\frac{1}{2}$ inches between the necks, $3\frac{1}{4}$ between the key-holes, the necks $1\frac{1}{2}$ inch long, and the tenons at each end of the same length, exactly square, that the socket may fit every way alike.
2 sockets, one for each tenon, such as appears on one end of fig. 4. The distance between the outside of

the straps with the nails in, must be $5\frac{1}{4}$ inches; fig. 5 is an end view of it, and the band that drives over it at the end of the shaft, as they appear on the end of the conveyer.

2 small 3-4 inch gudgeons for the other ends of the conveyers.

4 thin bands $5\frac{1}{2}$ inches from the outsides, for the conveyers.

1 gudgeon an inch thick, neck $3\frac{1}{4}$ inches, and tang. 10 inches, for the shaft in the upper pulley and next to it; but if a gudgeon be put through the pulley, let it be of the form of fig. 6, with a tenon and socket at one end, like fig. 4.

1 harness-buckle, $3\frac{1}{2}$ inches from the outsides, with two tongues; such as fig. 12, pl. 6.

Add whatever more small gudgeons and bands may be necessary for giving motion.

For a Hopper-Boy.

1 piece of dry, hard, clean, pine scantling, $4\frac{1}{2}$ by $4\frac{1}{2}$ inches, and 10 feet long, for the upright shaft.

1 piece of dry poplar, soft pine, or other soft light wood, not subject to crack and split in working, 8 by $2\frac{1}{2}$ inches, 15 or 16 feet long, for the flight arms.

Some 2 inch plank for wheels to give it motion, and scantling $4\frac{1}{2}$ by $4\frac{1}{2}$ inches for the shafts.

60 flights 6 inches long, 3 inches wide, and 1-2 inch at one, and 1-4 at the other edge, thinner at the fore than hind end, that they may drive in tight like a dovetail wedge. These may be made out of green hard maple, split from sap to heart, and set to dry.

Half a common bed-cord, for a leading line, and balance rope.

Smith's Bill of Iron.

1 stay-iron, C F E, plate VII, fig. 12. The height from the top of the ring F, to the bottom of the feet C E, is 15 inches; distance of the points of the feet C E 24 inches; size of the legs 1-2 by 3-4 inch; size of the ring F 1 by 1-4 inches, round and smooth inside; 4 inches diameter, the inside corners rounded off, to

keep it from cutting the shaft; there must be two little loops or eyes, one in each quarter, for the balance rope to be hung to either that may suit best.

2 screws (with thumb-burrs that are turned by the thumb and fingers) 1-4 of an inch thick, and 3 inches long, for the feet of the stay-iron.

2 do. for the end flights, $3\frac{1}{2}$ inches long, rounded $1\frac{1}{2}$ inch next the head, and square $1\frac{1}{4}$ inch next the screw, the round part thickest.

2 do. for the end sweepers, $6\frac{1}{4}$ inches long, rounded 1 inch next the head, 1-4 inch thick.

2 do. for the hopper sweepers, $8\frac{1}{2}$ inches long and 1-4 inch thick, (long nails with rivet heads will do.)

1 step-gudgeon (fig. 15), $2\frac{1}{2}$ inches long below the ring, and tang 9 inches, 3-4 inch thick.

1 plate 4 by 4, and 1-8 inch thick, for the step-gudgeon to pass through, (fig. 14.)

1 band for the step-gudgeon, $3\frac{3}{4}$ inches diameter; from the outsides it has to pass through the stay-iron.

1 gudgeon and band, for the top of the shaft, gudgeon 3-4 inch, band 4 inches diameter from the outsides.

The smith can, by the book, easily understand how to make these irons; and the reader may, from these bills of materials, make a rough estimate of the whole expense, which he will find very low compared with their utility.

ART. 103.

A MILL FOR CLEANING AND HULLING RICE.

Plate X, fig. 2. The rice brought to the mill in boats, is to be emptied into the hopper 1, out of which it is conveyed, by the conveyer, into the elevator at 2, which elevates it into the garner 3; on the third floor it descends into the garner 4, that hangs over the stones 5, and supplies them regularly. The stones are to be dressed with a few deep furrows, with but little draught, and picked full of large holes; they must be set more than the length of the grain apart. The hoop should be

lined inside with strong sheet-iron and if punched full of holes it will do better. The grain is kept under the stone as long as necessary, by causing it to rise some distance up the hoop, to get out through a hole, which is to be made higher or lower by a gate, sliding in the bottom of it.

The principle by which the grain is hulled, is that of rubbing them against one another with great force, between the stones, by which means they hull one another without being broke by the stones, near as much as by the usual way.* As it passes through the stones 5, it should fall into a rolling-screen or shaking-sieve 6, made of wire, with such meshes as will let out, at the head, all the sand and dust, which may be let run through the floor into the water, if convenient; and to let the rice and most of the heavy chaff fall through into the conveyer, which will convey it into the elevator at 2. The light chaff, &c. that does not pass through the sieve, will fall out at the tail, and if useless may also run into the water and float away. There may be a fan put on the spindle, above the trundle, to make a light blast, to blow out the light chaff and dust, which should be conveyed out through the wall; and this fan may supercede the necessity of the shaking-sieve. The grain and heavy chaff are elevated into garner 7, thence it descends into garner 8, and passes through the stones 9, which are to be fixed and dressed the same way as the others, and are only to rub the grain harder; the sharpness on the outside of the chaff (which nature seems to have provided for the purpose), will cut off all the inside hull from the grain, and leave it perfectly clean; then, as it falls from these stones it passes through the wind of the fan 10, fixed on the spindle of the stones 9, which will blow out the chaff and dust, and drop them in the room 21; the wind should escape through the wall. There

* By trying many experiments, and with much labour, striving to invent a new machine for rubbing the dust off the grains of wheat, and breaking the lumps of dust mixed with wheat that is trod on the ground; and for shelling off the white caps, breaking the rotten, fly-eaten, and smut grains, and to break the garlic, &c. I discovered this principle; which I afterwards used with a common pair of burr mill-stones, properly dressed for grinding wheat, and always found it to succeed well, without breaking any good grains, grinding the white caps to fine dust.

is a regulating board that moves on a joint at 21, so as to take all the grain into the conveyer, which will convey into the elevator at 11, which elevates it into the garner 12, to pass through the rolling-screen 13, which should have wire of 3 sized meshes; first, to take out the dust, to fall into a part 17, by itself; second, the small rice into an apartment 16; the whole grains fall into garner 14, perfectly clean, and are drawn into barrels at 15. The fan 18 blows out the dust, and lodges it in the room 19, and the wind passes out at 20; the head rice falls at the tail of the screen, and runs into the hopper of the stones 5, to go through the whole operation again. Thus the whole is completely done by the water, by the help of the machinery from the boat, until ready to put into the barrel, without the least manual labour.

Perhaps it may be necessary to make a few furrows in the edge of the stone, slanting, at an angle of about 30 degrees with a perpendicular line, these furrows will throw up the grain next the stone, on the top of that in the hoop, which will change its position continually, by which means it will be better cleaned; but this may probably be done without.

D

is a machine [illegible] that moves on a shaft [illegible] so as to take [illegible] the rain into the conveyer, which will convey into the [illegible] elevator [illegible] the garner 18; [illegible] passes through the [illegible] screen [illegible] should [illegible] the [illegible] to fall into a [illegible] rice into [illegible] the whole [illegible] into garner [illegible] perfectly clean, and are drawn [illegible] barrels at 16. The [illegible] is in the [illegible] 19, and the [illegible] falls at the tail of [illegible] hopper of the stones 5, to [illegible] again. Thus the [illegible] water, by the help of the machinery, from the [illegible] ready to put into the [illegible] [illegible]

Perhaps it may be [illegible] in the edge of the stone, [illegible] an angle of about 20 degrees [illegible] in the [illegible] hoop, which will change [illegible] which means it will [illegible] ably be done without [illegible]

[illegible]

PART IV.

THE

YOUNG MILLER'S GUIDE;

CONTAINING

THE WHOLE PROCESS

OF THE

ART OF MANUFACTURING GRAIN INTO FLOUR;

EXPLAINED, IN ALL ITS BRANCHES,

ACCORDING TO THE MOST IMPROVED PLANS PRACTISED IN THE BEST MERCHANT AND FLOUR MILLS IN AMERICA.

CONTENTS OF PART IV.

CHAP. I.—The principles of grinding, and rules for draughting the furrows of mill-stones.

CHAP. II.—Directions for furrowing and hanging a new pair of burr-stones ready for grinding, and keeping them in good face, for sharpening them and grinding to the right fineness; so as to clean the bran well, and make but little coarse flour.

CHAP. III.—Of Garlic,—with directions for grinding wheat mixed with it, and dressing the stones suitable thereto.

CHAP. IV.—Of grinding the middlings, and other coarse flour over again, to make the best profit of them.

CHAP. V.—Of the quality of stones to suit the quality of the wheat.

CHAP. VI.—Of bolting-reels and cloths, with directions for bolting and inspecting flour.

CHAP. VII.—Of the duty of the miller, in keeping the business in order.

Peculiar accidents by which mills are subject to take fire.

Of improving mill-seats.

CONTENTS OF PART II.

CHAP. I.—The quantity of [illegible] inking, and [illegible] to [illegible] the fineness of ink [illegible].

CHAP. II.—Directions for forming and keeping [illegible] of [illegible] ready for grinding and keeping them in good faces, [illegible] preparing them and grinding [illegible] the right [illegible] [illegible] [illegible] [illegible] and [illegible] make bad [illegible].

CHAP. III.—Of [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

CHAP. IV.—Of [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] of them.

CHAP. V.—Of the [illegible] [illegible] [illegible] of the [illegible].

CHAP. VI.—Of [illegible] [illegible] with directions [illegible].

CHAP. VII.—Of [illegible] [illegible] [illegible].

THE

YOUNG MILLER'S GUIDE.

PART THE FOURTH.

CHAPTER I.

ART. 104.

THE PRINCIPLES OF GRINDING EXPLAINED, WITH SOME OBSERVATIONS ON LAYING OUT THE FURROWS IN THE STONES, WITH A PROPER DRAUGHT.

THE end we have in view, in grinding the grain, is, to reduce it to such a degree of fineness, as is found by experience to make the best bread, and to put it in such a state, that the flour may be most effectually separated from the bran or skin of the grain, by means of sifting or bolting; and it has been proved by experience, that to grind the grain fine with dull mill-stones, will not answer said purpose well, because it kills or destroys that lively quality of the grain, that causes it to ferment and raise in the baking; it also makes the meal so clammy, that it sticks to the cloth, and chokes up the meshes in bolting. Hence, it appears, that it should be made fine with as little pressure as possible; and it is evident, that this cannot be done without sharp instruments. Let us suppose we undertake to operate on one single grain, I think it seems reasonable that we should first cut it into several pieces, with a sharp instrument, to put it in a state suitable for being passed between two planes, in order to be reduced to one regular fineness. The planes

should have on their faces a number of little sharp edges, to scrape off the meal from the bran, and be set at such a distance as to reduce the meal to the required fineness, and no finer, so that no part can escape unground. The same rules or principles will serve for a quantity that will serve for one grain.

Therefore, to prepare the stones for grinding to the greatest perfection, we may conclude that their faces must be put in such order, that they will first cut the grain into several pieces, and then pass it between them, in such a manner, that none can escape without being ground to a certain degree of fineness, and at the same time scrape the meal off clean from the bran or skin.

1. The best way that I have yet found to effect this is, (after the stones are faced with the staff and the pick,) to grind a few quarts of sharp fine sand; this will face them to fit each other so exactly, that no meal can pass between them without being ground; it is also the best way of sharpening all the little edges on the face, that are formed by the pores of the stone, (but instead of sand, water may be used, the stones then face each other) so that they will scrape the meal off of the bran, without too much pressure being applied. But as the meal will not pass from the centre to the periphery or verge of the stones, soon enough, without some assistance, there must be a number of furrows, to assist it in its egress; and these furrows must be set with such a draught, that the meal will not pass too far along them at once, without passing over the land or plane, lest it should get out unground. They should also be of sufficient depths, to admit air enough to pass through the stones to carry out the heat generated by the friction of grinding; but if they have too much draught, they will not bear to be deep, for the meal will escape along them unground. These furrows ought to be made sharp at the feather edge (which is the hinder edge of the furrow, and the foremost edge of the land), which serves the purpose of cutting down the grain; they should be more numerous near the centre, because there the office of the stone is to cut the grain, and near the periphery their office is (that of the two planes) to reduce the flour

to its required fineness, and scrape the bran clean by the edges, formed by the numerous little pores with which the burr stone abounds. However, we must consider, that it is not best to have the stones too sharp near the eye, because they then cut the bran too fine. The stones incline to keep open near the eye, unless they are too close. If they are porous (near the eye) and will keep open without picking, they will always be a little dull, which will flatten the bran, without cutting it too much. Again, if they be soft next the eye, they will keep too open, and that part of the stone will be nearly useless. Therefore they should be very hard aud porous.

It is also necessary, that we dress the face of the stone in such a form, as to allow room for the grain or meal, in every stage of its passage between the stones. In order to understand this, let us conceive the stream of wheat, entering the eye of the stone, to be about the thickness of a man's finger, but instantly spreading every way over the whole face of the stone; therefore this stream must get thinner, as it approaches the periphery (where it would be thinner than a fine hair, if it did not pass slower as it becomes finer, and if the stones were not kept apart by the bran), for this reason, the stones must be dressed so, that they will not touch at the centre, within about a 16th or 20th part of an inch, but to get closer gradually, till within about 10 or 12 inches from the verge of the stone, proportioned to the diameter, and from that part out they must fit nicely together. This close part is called the flouring of the stone. The furrows should be deep near the centre, to admit wheat in its chopped state, and the air, which tends to keep the stones cool.*

* It is asserted by some (and I believe, not without reason) that it is absolutely necessary to have a bridge-tree that shall have a degree of elasticity, which gives the stone a tremulous motion up and down, and therefore effects a trituration more completely, making more lively flour than it would do, supposing the bridge-tree to be a solid immoveable rock. But what is the proper degree of elasticity, or size of a bridge-tree, suitable to the weight of the stone, I know not; not having experienced this matter sufficiently to give an opinion on it; but I am inclined to think that this is an error.

One disadvantage in having a very elastic bridge-tree is, when the stones run empty, they come together with more force, and heat quicker; and if once made red hot, it totally destroys the good sharp quality of the burr, as far as the heat penetrates.

ART. 105.

OF THE DRAUGHT NECESSARY TO BE GIVEN TO THE FURROWS OF MILL-STONES.

From these principles and ideas, and the laws of central forces, explained art. 13, I form my judgment of the proper draught of the furrows, and the manner of dress, in which I find but few of the best millers to agree; some prefer one kind, and some another, which shows that this necessary part of the miller's art is not yet generally well understood. In order that this matter may be more fully discussed and better understood, I have constructed fig. 3, plate XI. AB represents the eight quarter, CD the twelve quarter, and EA the central dress. Now we observe that in the eight quarter dress, the short furrows at F have about five times as much draught as the long ones, and cross one another like a pair of shears, opened so wide that they will drive all before them, and cut nothing; and if these furrows be deep they will drive out the meal as soon as it gets into them, and thereby make much coarse meal, such as middlings and ship stuff or carnel; the twelve quarter dress appears to be better; but the short furrows at G have about four times as much draught as the long ones, the advantage of which I cannot yet see, because if we have once found the draught that is right for one furrow, so as to cause the meal to pass through the stone in a proper time, it appears reasonable that the draught of every other furrow should be equal to it.

In the central dress EA the furrows have all one draught, and if we could once determine how much is necessary exactly, then we might expect to be right, and I presume we will find it to be in a certain proportion to the size and velocity of the stone; because the centrifugal force that the circular motion of the stones gives the meal, has a tendency to move it outward, and this force will be in inverse proportion to the diameter of the stones, their velocities being the same by the 4th law of circular motion. E e is a furrow of the running stone, and we may see by the figure, that the furrows cross one another at the centre in a much greater angle

than near the periphery, which I conceive to be right, because the centrifugal force is much less nearer the centre than the periphery. But we must also consider, that the grain, whole or but little broken, requires less draught and central force to send it out, than it does when ground fine; which shows, that we must here differ in practice from the theories laid down in art. 13, founded on the laws of circular motion and central forces; because, the grain as it is ground into meal, is less affected by the central force to drive it out, therefore the angles with which the furrows cross each other must be greater than the verge or skirt of the stone, and less near its centre than assigned by theory, and this variation from theory can be formed only by conjecture, and ascertained by practice.

From the whole of my speculations on this difficult subject, added to my observations on my own and others' practice and experience, I attempt to form the following rule for laying out a five foot mill-stone. See fig. 1. Pl. XI.

1. Describe a circle with 3 inches, and another with 6 inches radius, round the centre of the stone.
2. Divide the 3 inches space between these two circles, into 4 spaces, by 3 circles equi-distant, call these five circles draught circles.
3. Divide the stone into 5 parts, by describing 4 circles equi-distant between the eye and the verge.
4. Divide the circumference of the stone into 18 equal parts, called quarters.
5. Then take a straight edged rule, lay one end at one of the quarters at 6, at the verge of the stone, and the other end at the outside draught circle, 6 inches from the centre of the stone, and draw a line for the furrow from the verge of the stone to the circle 5. Then shift the rule from draught circle 6, to the draught circle 5, and continue the furrow line towards the centre, from circle 5 to 4: then shift in the rule to draught circle 4, and continue to 3; shift to 3 and continue to 2; shift to two, and continue to one, and the curve of the furrow is formed, as 1—6 in the figure.
6. To this curve form a pattern to lay out all the rest by.

The furrows with this curve will cross each other with the following angles, shown fig. I,

at circle 1, which is the eye of the stone at	75	degrees angle.
— 2 - -	45	——
— 3 - -	35	——
— 4 - -	31	——
— 5 - -	27	——
— 6 - -	23	——

These angles, I think, will do well in practice, will grind smooth, and make but little coarse meal, &c. as shown by the lines G r, H r, G s, H s, &c. &c.

Supposing the greatest draught circle to be 6 inches radius, then by theory the angles would have been

at circle 1 - -	138	degrees angle.
— 2 - -	69	——
— 3 - -	46	——
— 4 - -	34,5	——
— 5 - -	27,5	——
— 6 - -	23	——

If the draught circle had been 5 inches radius, and the furrows straight, the angles would then have been at

	circle		degrees.
	1	about	180
And 6 inches from centre, as shown by lines G 1, H 1.		—	110
	2	—	60
	3	—	38
	4	—	29
	5	—	23
	6	—	18

The angles near the centre here, are quite too great to grind; they will push the grain before them; therefore, to remedy all these disadvantages, take the aforesaid rule, which forms the furrows, as shown at 6—7, fig. 1, which is 4 of 18 qrs. H 8 represents a furrow of the runner, showing the angles where they cross those of the bed-stone, in every part. Here I have supposed the extremes of the draught to be 6 inches for the verge, and 3 inches for the eye of the stone, to be right for a stone 5 feet diameter, revolving 100 times in a minute;

but of this we cannot be certain. Yet by experience and practice the extremes may be ascertained in time for all sizes of stones, with different velocities, no kind of dress that I can conceive, appearing to me likely to be brought to a truth except this, and it certainly appears both by inspecting the figure, and reason, that it will grind the smoothest of all the different kinds exhibited in the plate.

The principle of grinding is partly that of shears clipping. The planes of the face of the stones serving as guides to keep the grain, &c. in the edge of the shears, the furrows and pores, forming the edges; if the shears cross one another too short, they cannot cut; this shows that all strokes of the pick should be parallel to the furrows.

To give two stones of different diameters the same draught, we must make their draught circles in direct proportion to their diameters; then the furrows of the upper and lower stones of each size, will cross each other with equal angles in all proportional distances, from their centres, to their periphery: See art. 13. But when we come to consider that the mean circles of all stones are to have nearly equal velocities, and that their central forces will be in inverse proportion to the diameters; we must consider, that small stones must have much less draught than large ones, in proportion to their diameters. See the proportion for determining the draught, art. 13.

It is very necessary that the true draught of the furrows, should be determined to suit the velocity of the stone; because the centrifugal force of the meal will vary, as the squares of the velocity of the stone, by the 5th law of circular motion. But the error of the draught may be corrected, in some measure, by the depth of the furrows. The less the draught, the deeper the furrow; and the greater the draught, the shallower must the furrow be to prevent the meal from escaping unground. But if the furrows be too shallow, there will not a sufficient quantity of air pass through the stones to keep them cool. But in the central dress the furrows meet so near together that they cut the stone too much away

at the centre, unless they are made too narrow; therefore, I prefer what is called the quarter dress; but divided into so many quarters, that there will be little difference between the draught of the furrows; suppose 18 quarters in a 5 foot stone; then each quarter takes up about $10\frac{1}{2}$ inches of the circumference of the stone; which suits to be divided into about 4 furrows and 4 lands, if the stone be close; but if it be open, 2 or 3 furrows to each quarter will be enough. This rule will give 4 feet 6 inch stones, 16; and 5 feet 6 inch stones, 21; and 6 feet stones, 23 quarters. But the number of quarters is not so particular, but better more than less. If the quarters be few, the disadvantage of the short furrows crossing at too great an angle, and throwing out the meal too coarse, may be remedied, by making the land widest next the verge, thereby turning the furrows towards the centre, when they will have less draught, as in the quarter H I, fig. 3.

CHAPTER II.

Directions for facing a pair of new burr stones, laying out the furrows, hanging them for grinding, and for keeping them in good face; picking and sharpening them; for grinding to the right fineness, so as to clean the bran well, and make but little middlings, &c.

ART. 106.

OF FACING MILL-STONES.

THE burr mill-stones are generally left in such face by the maker, that the miller need not spend much labour and time on them with picks, before he may hang, and grind water or dry sand, with them, because he can make much better speed by this method. After they have ground a quantity, that may be judged sufficient, they must be taken up, and the red staff tried over their

faces,* and if it touches in circles, the red parts should be well cracked with picks, then put them to grind a small quantity of water or sand again; after this take them up, and try the staff on them, picking off the red parts as before, and repeat this operation, until the staff will touch nearly alike all the way across, and until the stone comes to a face in every part, that the quality thereof may plainly appear; then, with a red or black line proceed to lay out the furrows, in the manner determined upon, from the observations already laid down in ch. I. But here we must observe that the edges do the grinding, and that the quantity ground will be in proportion to the number of edges that are to do it. After having a fair view of the face and quality of the stone, we can judge of the number of furrows most suitable, observing, that where the stone is most open and porous, few furrows will be wanted; but where it is close and smooth, the furrows ought to be more numerous, and both they and the lands narrow, (about 1 and 1-8 of an inch wide) that they may form the more edges, to perform the grinding. The furrows, at the back, should be made nearly the depth of the thickness of a grain of wheat, but sloped up to a feather edge, not deeper than the thickness of a finger-nail;† this edge is to be made as sharp as possible, which cannot be done without a very sharp, hard pick. When the furrows are all made, try the red staff over them, and if it touches near the

* The red staff is longer than the diameter of the stones, and three inches thick on the edge, which is made perfectly straight, on which is rubbed red clay, mixed with water; which shows the highest parts of the faces of the stones, when rubbed over them, by leaving the red on those high parts.

† For the form of the bottom of the furrow, see plate XI. fig. 3. The curve line e b shows the bottom, b the feather edge, and e the back part. If the bottom had been made square at the back as at e, the grain would lay in the corner, and by the centrifugal force, would work out along the furrows without passing over the lands, and part would escape unground. The back edge must be sloped for two reasons; 1st, that the meal may be pushed on to the feather edge; 2d, that the furrow may grow narrower, as the face of the stones wears away, to give liberty to sharpen the feather edge, without making the furrows too wide. Fig. 5. represents the face of two stones, working together, the runner moving from a to d. When the furrows are right over one another as at a, there is room for a grain of wheat; when they move to the position of b, it is flattened, and at c, is clipped in two by the feather edges, and the lands or planes operate on it as at d.

centre, the marks must be quite taken off about a foot next to it, but observing to crack lighter the farther from it, so that when the stones are laid together, they will not touch at the centre, by about one twentieth part of an inch, and close gradually, so as to touch and fit exactly, for about 10 or 12 inches from the verge. If the stones be now well hung, having the facing and furrowing neatly done, they will be found in the most excellent order for grinding wheat, that they can possibly be put in, because they are in good face, fitting so neatly together, that the wheat cannot escape unground, and all the edges being at their sharpest, so that the grain can be ground into flour, with the least pressure possible.

ART. 107.

OF HANGING MILL-STONES.

If the stone have a balance-ryne it is an easy matter to hang it, for we have only to set the spindle perpendicular to the face of the bed-stone; which is done by fastening a staff on the cock-head of the spindle, so that the end may reach to the edge of the stone, and be near the face. In this end we put a piece of whale-bone or quill, so as to touch the stone, that, when one turns the trundle-head, the quill will move round the edge of the stone, and when it is made to touch alike all the way round, by altering the wedges of the bridge, the stone may be laid down and it will be ready hung;* but if we have a stiff-ryne, it will be much more difficult, because we have not only to fix the spindle perpendicular to the

* But here we must observe, whether the stone be of a true balance, as it hangs on the cock head, and if not, it must be truly balanced, by running lead into the lightest side. This ought to be carefully attended to by the maker, because the stone may be made to balance truly when at rest; yet, if every opposite part does not balance each other truly, the stone may be greatly out of balance when in motion, although truly balanced when at rest; and this is the reason why the bush of some stones cannot be kept tight but a few hours, while others will keep tight several months, the spindles being good, and stones balanced when at rest. The reason why a stone that is balanced at rest, will sometimes not be balanced in motion, is, that if the upper side be heaviest on one side, and the lowest side be heaviest on the other side of the centre, the stone may balance at rest, yet, when set in motion, the heaviest parts draw outwards most by the centrifugal force, which will put the stone out of balance while in motion; and if

face of the bed-stone, but we must set the face of the runner perpendicular to the spindle, and all this must be done to the greatest exactness, because the ryne being stiff, will not give way to suffer the runner to form itself to the bed-stone, as will the balance-ryne.

The bed of the ryne being first carefully cleaned out, the ryne is put into it and tied, until the stone is laid down on the cock-head; then we find the part that hangs lowest, and, by putting the hand thereon, we press the stone down a little, turning it about at the same time, and observing, whether the lowest part touches the bed-stone equally all the way round; if it does not, it is adjusted by altering the wedges of the bridge-tree, until it touches equally, and then the spindle will stand perpendicular to the face of the bed-stone. Then, to set the face of the runner perpendicular or square to the spindle, we stand in one place, turning the stone, and pressing on it at every horn of the ryne, as it passes, and observing whether the runner will touch the bed-stone equally, at every horn, which, if it does not, we strike with an iron bar on the horn, that bears the stone highest, which, by its jarring, will settle itself better into its bed, and thereby let the stone down a little in that part; but if this be not sufficient there must be paper put on the top of the horn, that lets the stone too low; observing to mark the high horns, that when the stone is taken up, a little may be taken off the bed, and the ryne will soon become so neatly bedded, that the stone will hang very easily. But I have ever found the bridge to be a little out of place, or in other words the spindle moved a little from its true perpendicular position, with respect to the face of the bed-stone, at every time the stone is

the stone be not round, the parts farthest from the centre will have the greatest centrifugal force, because the centrifugal force is as the square of the distance from the centre. The neck of the spindle will wear next the longest side, and get bush loose; and this argues in favour of a stiff ryne. The best method that I have heard of for hanging stones with stiff horned rynes, appears to be as follows. Fix a screw to each horn to regulate by, which is done thus—after the horns are bedded, sink under each horn a strong burr, through which the screw is to pass from the back of the stone, and fasten them in with lead; then, after the stone is laid down, put in the screws from the top of the stone, screwing them till the points bear tight on the horn: then proceed to hang the stone, which is very easily done, by turning the screws.

taken up; which is a great objection to the stiff horn ryne; for if the spindle be but very little out of place, the stones cannot come together equally; whereas if it be considerably out of place with a balance ryne, it will be little or no injury to the grinding, because the running stone has liberty to form itself to the bed-stone.

ART. 108.

OF REGULATING THE FEED AND WATER IN GRINDING.

The stone being well hung, proceed to grind, and when all things are ready, draw as much water as is judged to be sufficient; then observe the motion of the stone, by the noise of the damsel, and feel the meal; and if it be too coarse, and the motion too slow, give less feed, and she will grind finer, and the motion will be quicker; if it grind too coarse yet, lower the stone; then if the motion be too slow draw a little more water; but if the meal feel to be too low ground, and the motion right, raise the stone a little, and give a little more feed. If the motion and feed be too great, and the meal be ground too low, shut off part of the water.

But if the motion be too slow, and feed be to small, draw more water.

To regulate the grinding to suit the quantity of water, the following rule is set in verse, that it may be more easily remembered.*

RULE.

If the motion be too great,
Then add a little feed and weight;
But if the motion be too slow,
Less feed and weight will let her go.

But here the miller must remember, that there is a certain portion of feed that the stones will bear and grind

* The miller should, by many experiments, find the quantity of water that best suits his mill, and have a mark made on the staff by which he draws the gate, that he may draw a suitable quantity at once.

well; which will be in proportion to the size, velocity and sharpness of them, and if this be exceeded, there will be a loss by not having the grinding well done. But no rule can be laid down, to ascertain this portion of feed; it must be attained by practice;* as must also the art of judging of the right fineness. I may, however, lay down such rules and directions as may be of some assistance to the young beginner.

ART. 109.

RULE FOR JUDGING OF GOOD GRINDING.

Catch your hand full of the meal as it falls from the stones, and feel it lightly between your fingers and thumb; and if it feels smooth and not oily or clammy, and will not stick much to the hand, it shows it to be fine enough, and the stones to be sharp. If there be no lumps to be felt larger than the rest, but all of one fineness, it shows the stones to be well faced, and the furrows to have not too much draught, as none has escaped unground.

But if the meal feels very smooth and oily, and sticks much to the hand, it shows it to be too low ground, hard pressed and the stones dull.

But if it feels part oily, and part coarse and lumpy, and will stick much to the hand, it shows that the stones have too much feed; or, that they are dull, and badly faced, or have some furrows that have too much draught; or are too deep, or perhaps too steep at the back edge, as part has escaped unground, and part too much pressed and low.

Catch your hand full, and holding the palm up, shut it briskly; if the greatest quantity of the meal fly out and escape between your fingers, it shows it to be in a fine and lively state, the stones sharp, the bran thin, and will bolt well: But the greater the quantity that stays in the hand, the more it shows the reverse.

* If the stones be over-fed, it is not possible that the bran should be well cleaned, because the sharp edges on the face of the stone, that is made for the purpose of scraping the bran clean, is kept from it by the quantity of meal that is between the stones.

Catch a hand full of meal in a sieve, and sift the meal clean out of the bran; then feel it, and if it feels soft and springing, or elastic, and also feels thin, with but little sticking to the inside of the bran, and no pieces found much thicker than the rest, will show the stones to be sharp, and the grinding well done.*

But if it is broad and stiff, and the inside white, it is a sure sign that the stones are dull or overfed. If you find some parts that are much thicker and harder than the rest, such as almost half or quarter grains, it shows that there are some furrows that have too much draught, or are too deep or steep, at the back edge; else, that you are grinding with less feed than the depth of the furrows, and velocity of the stone will bear.

ART. 110.

OF DRESSING AND SHARPENING THE STONES WHEN DULL.

When the stones get dull they must be taken up, that they may be sharpened; to do this in the best manner, we must be provided with sharp hard picks, with which the feather edge of the furrows are to be dressed as sharp as possible; which cannot be done with soft or dull picks. The bottoms of the furrows are likewise to be dressed, to keep them of the proper depth; but here the dull picks may be used.† The straight staff must now also be run over the face carefully, and if there be any parts harder or higher than the rest, the red will be left on them; which must be cracked lightly, with many cracks, to make them wear as fast as the softer parts, in order to keep the face good. These cracks do also form

* Instead of a sieve, you may take a shovel and hold the point near the stream of meal, and it will catch part of the bran, with but little meal mixed with it; which may be separated by tossing it from one hand to the other, wiping the hand at each toss.

† To prevent the steel from striking your fingers, take a piece of leather about 5 by 6 inches square, make a hole through the middle, and put the handle of the pick through it, keeping it between your hands and the pick, making a loop in the lower edge, through which put one of your fingers, to keep up the lower part from the stone.

edges that help to clean the bran; and the harder and closer the stone, the more numerous are they to be. They are to be made with a very sharp pick, parallel to the furrows; and the damper the grain, the more the stone is to be cracked, and the drier and harder, the smoother must the face be. The hard smooth places which glaze, may be made to wear more evenly, by striking them, either with a smooth or rough faced hammer many light strokes, until a dust begins to appear, which frets the flinty part, and makes it softer and sharper. The stone will never be in the best order for cleaning the bran, without first grinding a little sand, to sharpen all the little edges formed by the pores of the stone; the same sand may be used several times. The stones may be sharpened without being taken up, or even stopped, viz. take half a pint of sand, and hold the shoe from knocking, to let them run empty; then pour in the sand, and this will take the glaze off the face, and whet up the edges so that they will grind considerably better: this ought to be often done.*

Some are in the practice of letting stones run for months without being dressed; but I am well convinced that those who dress them well twice a week, are well paid for their trouble.

ART. 111.

OF THE MOST PROPER DEGREE OF FINENESS FOR FLOUR.

As to the most proper degree of fineness for flour, millers differ in their opinion; but a great majority, and many of the longest experience, and best judgment,

* But care should be taken to prevent the sand from getting mixed with the meal; it should be catched in some vessel, the stone being suffered to run quite empty; the small quantity that will remain in the stone will not injure the flour. But I do not wish to encourage a lazy miller, to neglect taking up the stone.

When stones are first set to grind, they incline to raise, and grind coarser for a considerable time, the true reason of which is difficult to assign. Some attribute it to the expansion of the metal in the spindle; it has been suggested to me, that it is the steam, or the rarification of the air, by the heat produced by the action of the stones, which, not having a perfectly free passage to escape, bears up a part of the weight of the stone; and this cause will increase, until the stones are heated to the greatest degree.

agree in this; that, if the flour be made very fine, it will be killed (as it is termed); so that it will not raise, or ferment so well in baking; but I have heard several millers of good judgment, give it as their opinion, that flour cannot be made too fine, if ground with sharp clean stones; provided they are not suffered to rub against each other; and some of those millers do actually reduce almost all the meal they get out of the wheat into superfine flour; by which means they have but two kinds, viz. superfine flour, and horse feed, which is what is left after the flour is made, and is not fit to make even the coarsest kind of ship-bread.

I have tried the following experiment, viz. I contrived to catch as much of the dust of flour that was floating about in the mill, as made a large loaf of bread, which was raised with the same yeast, and baked in the same oven, with other loaves, that were made out of the most lively meal; when the loaf made of the dust of the flour was equally light, and as good, if not better than any of the others; it being the moistest, and pleasantest tasted, though made of flour that felt like oil, it being so very fine.

I therefore conclude, that it is not the degree of fineness that destroys the life of the flour, but the degree of pressure applied on it in grinding; and that flour may be reduced to the greatest degree of fineness, without injuring the quality; provided, it be done with sharp clean stones, and little pressure.*

* It might be difficult to assign the true reason why pressure or heat has such an effect on flour, as to destroy that life or principle, that causes it to ferment and raise in the baking—But we may form a few conjectures.

Query, may not this life be that vegetative quality that causes the grain to grow, seeing it is a fact known by experience, that if the grain be damaged, either by wet or heating in a heap so as to destroy its vegetation, that the flour that is made thereof will not bake well? And I presume, that if grain be heated by any means, so as to destroy its vegetative quality, it will not make flour that will have an easy fermentation; and it is probable, that this degree of heat is generated by the act of grinding when great pressure is applied, which cannot be avoided if the stones be dull.

But again, if we consider that most bodies are in part composed of air, which is in a solid and fixed state, and constitutes a proportional part of their weight, and this proportion is different in different species of matter, from 1-16 to 1-2, and in one species of wheat has been found, by experiments, to be 1-5 of its whole weight; that is, 12lb. of fixed air in 60lb. or one bushel of wheat. Now this air is roused into action two ways, viz. by fermentation and by heat, and as fast as it is roused, it instantly leaves the

CHAPTER III.

ART. 112.

OF GARLIC, WITH DIRECTIONS FOR GRINDING WHEAT MIXED THEREWITH; AND FOR DRESSING THE STONES SUITABLE THERETO.

IN many parts of America there is a species of onion called garlic, that grows spontaneously with the wheat. It bears a head resembling a seed onion, which contains a number of grains about the size of a grain of wheat, but somewhat lighter.* It is of a glutinous substance, which very soon adheres to the stone (in grinding) in such a manner as to blunt the edges, that they will not grind to any degree of perfection. Therefore, as often as the stones become dull, we are obliged to take the

body, and expands itself into about a million times more space than it filled before, in the form of a dense body. See Martin's Philosophy. New cider contains a large portion of this fixed air, which flies off by fermentation, leaving the cask considerably emptied; and as soon as the fixed air is all gone, the fermentation ceases.

Query, Is not this fixed air the very soul of vegetation and fermentation, and may not the degree of heat generated by grinding with great pressure, set it in motion and cause it to leave the flour, thereby not only destroying its life, but greatly lessening its weight, to the great loss of the miller; who, although he expects by hard squeezing to gain profit, sustains loss? As a confirmation of this hypothesis, we may observe, that many experiments have been made, by weighing a quantity of wheat carefully, before it was ground, and then weighing every thing that it made in manufacturing, and we have found it to be lacking in weight from 1 to 5 lb. per bushel: which could not be accounted for any way better, than supposing the loss to be occasioned by the escape of the fixed air. Therefore, I conclude, that the stones ought to revolve slow and be kept sharp; and the larger they are, the slower will they require to go, and the lighter may they press the grain, and yet grind a sufficient quantity, and make the best flour.

* The complete separation of this garlic from the wheat, is so difficult, that it has hitherto baffled all our art. Those grains that are larger, and those that are smaller, can be separated by screens; and those that are much lighter, may be blown out by fans; but those that are of the same size, and nearly of the same weight, cannot be separated without putting the wheat in water, where the wheat will sink, and the garlic swim. But this method is too tedious for the miller to practise, except it be once a year, to clean up the headings, or the like, rather than lose the wheat that is mixed with the garlic, which cannot be otherwise sufficiently separated. Great care should be taken by the farmers to prevent this troublesome thing from getting root in their farms, which, if it does, it will be almost impossible ever to root it out again; because it propagates by both seed and root, and is very hardy.

runner up, and wash the glaze off with water, scrubbing the faces with stiff brushes, and drying up the water with cloths or sponges; this laborious operation must be repeated twice, or perhaps four times, in 24 hours; if there be about 10 grains of garlic in a handful of wheat.

To put the stones in the best order to grind garlicky wheat, they must be cracked roughly all over the face; and dressed more open about the eye, that they may not break the grains of garlic too suddenly, but gradually giving the glutinous substance of the garlic more time to incorporate itself with the meal, that it may not adhere to the stone. The rougher the face, the longer will the stones grind, because the longer will the garlic be in filling all the edges.

The best method that I have yet discovered for manufacturing garlicky wheat, is as follows, viz.

First, clean it over several times, in order to take out all the garlic that can be got out by the machinery, (which is easily done if you have a wheat elevator well fixed, as directed in art. 94, plate IX.) then chop or half grind it, which will break the garlic, (it being softer than the wheat) the moisture of which, will so diffuse itself through the chopped wheat, that it will not injure the stones so much, in the second grinding. By this means a considerable quantity can be ground, without taking up the stones. The chopping may be done at the rate of 15 or 20 bushels in an hour; and with but little trouble or loss of time; provided there be a meal-elevator that will hoist it up to the meal-loft, from whence it may descend to the hopper by spouts, to be ground a second time; when it will grind faster than if it had not been chopped. Great care should be taken, that it be not chopped so fine that it will not feed by the knocking of the shoe; (which would make it very troublesome) as likewise, that it be not too coarse, lest the garlic be not sufficiently broken. If the chopped grain could lay a considerable time, that the garlic may dry, it would grind much better.

But although every precaution be taken, if there be much garlic in the wheat, the bran will not be well

cleaned; besides, there will be much coarse meal made; such as middlings, and stuff; which will require to be ground over again, in order to make the most profit of the grain: this I shall treat of in the next chapter.*

CHAPTER IV.

ART. 113.

OF GRINDING OVER THE MIDDLINGS, STUFF AND BRAN, OR SHORTS, IF NECESSARY; TO MAKE THE MOST OF THEM.

ALTHOUGH we grind the grain in the best manner we possibly can, so as to make any reasonable despatch; yet there will appear in the bolting, a species of coarse meal, called middlings; and stuff, a quality between superfine and shorts; which will contain a portion of the best part of the grain: but in this coarse state they will make very coarse bread; consequently, will command but a low price. For which reason it is oftentimes more profitable to the miller to grind and bolt such over again, and make them into superfine flour, and fine middlings; this may easily be done by proper management.

The middlings are generally hoisted by tubs, and laid in a convenient place on the floor, in the meal-loft, near the hopper-boy, until there is a large quantity gathered: when the first good opportunity offers it is bolted over, without any bran or shorts mixed with it, in order to take out all that is already fine enough; which will pass through the superfine cloth. The middlings will pass through the middlings' cloth, and will then be round and lively, and in a state fit for grinding; being freed from the fine part that would have prevented it from feeding freely. The small specks of bran that were before mixed with it, being lighter than the rich round

* Timothy Kirk, of York Town, (Pennsylvania,) has communicated to me an invention of his, an improved fan, for cleaning wheat, the principle of which is, to blow the grain twice with one blast of wind; which, with some further improvements, appears to offer fair to effect a complete separation of the garlic from the wheat, and every other substance that is lighter than the grain.

part, will not pass through the middlings' cloth, but will pass on to the stuff's cloth. The middlings will, by this means, be richer than before; and when made fine, may be mixed with the ground meal, and bolted into superfine flour.

The middlings may now be put into the hanging garner, over the hopper of the stones; out of which it will run into the hopper, and keep it full, as does the wheat, provided the garner be rightly constructed, and a hole, about 6 by 6 inches made for it to issue out at. There must be a rod put through the bar that supports the upper end of the damsel, the lower end of which must reach into the eye of the stone, near to the bottom, and on one side thereof, to prevent the meal from sticking in the eye, which if it does it will not feed. The hole in the bottom of the hopper must not be less than four inches square. Things being thus prepared, and the stones being sharp and clean, and nicely hung, draw a small quantity of water, (for meal does not require above one-tenth part that grain does) taking great care to avoid pressure, because the bran is not between the stones now to prevent their coming too close together. If you lay on as much weight as when grinding grain, the flour will be killed. But if the stones be well hung, and it be pressed lightly, the flour will be lively, and will make much better bread, without being bolted, than it would before it was ground. As fast as it is ground, it may be elevated and bolted; but a little bran will now be necessary to keep the cloth open; and all that passes through the superfine cloth in this operation, may be mixed with what passed through in the first bolting of the middlings; and be hoisted up, and mixed (by the hopper-boy) regularly with the ground meal, and bolted into superfine flour, as directed art. 89.*

The stuff, which is a degree coarser than middlings, if it be too poor for ship bread, and too rich to feed

* But all this trouble and loss of time may be saved by a little simple machinery of late invention, that will cost but a few dollars, viz. As the middlings fall by the first bolting, let them be conveyed into the eye of the stone, and ground with the wheat, as directed art. 89, plate VIII.; by which means, the whole thereof may be made into superfine flour, without any loss of time, or danger of being too hard pressed for want of the bran to keep the stones apart. This mode I first introduced, and several others have since adopted it with approbation.

cattle on, is to be ground over in the same manner as the middlings. But if it be mixed with fine flour, (as it sometimes is,) so that it will not feed freely, it must be bolted over first; this will take out the fine flour, and also the fine specks of bran, which being lightest, will come through the cloth last. When it is bolted, the part that passes through the middlings' and stuff's parts of the cloth, are to be mixed and ground together; by which means the rich particles will be reduced to flour; and when bolted will pass through the finer cloths, and will make tolerable good bread. What passes through the middlings' cloth, will make but indifferent ship-bread, and what passes through the ship-stuff's cloth, will be what is called brown-stuff, roughings, or horse-feed.

The bran and shorts seldom are worth the trouble of grinding over, unless the stones have been very dull; or the grinding been but slightly performed; or the wheat very garlicky. For this purpose the stones are to be very sharp, and more water and pressure is here required, than in grinding grain. The flour that is made thereof, is generally of an indifferent quality, being made of that part of the grain that lies next the skin, and great part thereof, being the skin itself, cut fine.*

CHAPTER V.

ART. 114.

OF THE QUALITY OF MILL-STONES, TO SUIT THE QUALITY OF THE WHEAT.

IT has been found by experience, that different qualities of wheat require different qualities of stones, to grind to the best perfection.

* But the merchant miller is to consider, that there is a certain degree of closeness or perfection that he is to aim at in manufacturing, which will yield him the maximum, or greatest profit possible, in a given time. And this degree of care and perfection will vary with the prices of wheat and flour, so that what would yield the greatest profit at one time, would sink money at another; because, if the difference of the prices of wheat and flour be but little, then we must make the grain yield the most possible, to obtain any profit But if the price of flour be much above that of the wheat, then we had best make the greatest despatch, even if we should not do it so well, in order that the greater quantity may be done while

Although there be several species of wheat, of different qualities; yet with respect to the grinding, we may take notice of but the three following qualities, viz.

1. The dry and hard.
2. The damp and soft.
3. Wheat that is mixed with garlic.

When the grain that is to be ground to dry and hard, such as is raised on high, and clay lands; threshed in

other prices last; whereas, if we were to make such a despatch when the price of flour was but little above that of wheat, we would sink money.

A TABLE

Showing the product of a bushel of wheat of different weights and qualities, ascertained by experiments in grinding parcels.

Weight per bushel. lb.	Super-fine flour. lb.	Tail flour & middlings. lb.	Ship Stuff. lb.	Bread Stuff, shorts, & bran. lb.	Screenings and loss in grinding. lb.	Proof. lb.	Quality of the grain.
59,5	38,5	3,68	2,5	13,1	1,72	59,5	White wheat clean.
59	40,23	3,65	2,12	12	1	59	Do. do. well cleaned.
60	38,7	3,6	1,61	8,52	7,57	60	Red do. not well do.
61	39,7	5,68	2,4	9,54	3,68	61	White do. mixt with green garlic.
56	35,81	5	1,85	7,86	5,48	56	White do. very clean.
59,25	35,26	4,4	1,47	11,33	6,79	59,25	Red do. with some cockle & light grains.

If the screenings had been accurately weighed, and the loss in weight occasioned by the grinding ascertained, this table would have been more interesting. A loss of weight does take place by the evaporation of the moisture by the heat of the stones in the operation.

The author having conceived that if a complete separation of the skin of the wheat from the flour could be effected, and the flour reduced to a sufficient degree of fineness, it might all pass for superfine flour. After having made the experiments in the table, he made such improvements in the manufacture by dressing the mill-stones to grind smooth, and by means of the machinery which he invented, returning the middlings into the eye of the stone, to be ground over with the wheat, and elevating the tail flour to the hopper-boy to be bolted over again, &c. &c. That in making his last 2000 barrels of superfine flour he left no middlings nor ship-stuff but what was too poor for any kind of bread, excepting some small quantities which were retained in the mill, and the flour passed the inspection with credit. Others have since pursued the same principles and put them more fully and completely in operation. Thus the manufacture of flour has arrived nearly to a state of perfection, and those millers who had faith to believe, have for fourteen years past been enjoying themselves, seeing the machinery of their mills perform all the laborious parts of the work, and have been selling and eating good superfine flour; while those who had not, have been toiling, sweating, and doing the labour that the power of the water which moves their mills might have done, and have been selling and eating middlings and ship-stuff.

barns, and kept dry;* the stones for grinding such wheat, should be of that quality of the burr, that is called close and hard, with few large pores; in order that they may have more face. The grain being brittle and easy broken into pieces, requires more face or plane parts (spoken of in art. 104,) to reduce it to the required fineness, without cutting the skin too much.

When the grain that is to be ground is a little damp and soft, such as is raised on a light, sandy soil, tread out on the ground, and carried in the holds of ships to market, which tends to increase the dampness, the stones are required to be more open, porous, and sharp, because the grain is tough, difficult to be broke into pieces, and requires more sharpness, and less face (or plane surface) to reduce it to the required fineness.† See art. 104.

When there is more or less of the garlic, or wild onion, (mentioned art. 111.) mixed with the wheat, the stones will require to be open, porous and sharp; because the glutinous substance of the garlic adheres to the face of the stones, and blunts the edges; by which means little can be ground, before the stones get so dull that they will require to be taken up, and sharpened; and the more porous and sharp the stones are, the longer will they run, and the more will they grind, without getting dull. There is a quality of the burr stone which I shall for distinction call a mellow or soft quality, very different from the hard and flinty; these are not so subject to glaze on their face, and it is found by experience that stones of this quality will grind at one dressing

* Such wheat as is produced by the mountainous and clay lands of the country distant from the sea and tide waters, is generally of a brownish colour, the grain appearing flinty, and sometimes the inside a little transparent, when cut by a sharp knife. This transparent kind of wheat is generally heavy, and of a thin skin, and will make as white flour, and as much of it, as the whitest grain.

† Such is the wheat that is raised in all the low, level, and sandy lands, of countries near the sea and tide waters of America, where it is customary to tread out their wheat on the ground by horses, and it sometimes gets wet by rain and dew, and the dampness of the ground. This grain is naturally of a fairer colour, and softer; and when broken, the inside is white, which shows it to be nearer a state of pulverisation, and is more easily reduced to flour, and will not bear as much pressure as the grain that is raised on high and clay lands, or such, that when broken, appears solid and transparent

three or four times as much grain, mixed with garlic, as those of a hard quality.* See art. 111.

CHAPTER VI.

ART. 115.

OF BOLTING-REELS, AND CLOTHS; WITH DIRECTIONS FOR BOLTING AND INSPECTING THE FLOUR.

THE effect we wish to produce by sifting, or bolting, is to separate the different qualities of flour from each other; and from the skin, shorts, or bran. For this reason, let us consider the most rational means that we can use to attain this end.

Queries concerning Bolting.

1. Suppose that we try a sieve, the meshes of which are so large, as to let all the bran and meal through: now it is evident, that we could never attain the end proposed by the use thereof.

2. Suppose we try a finer sieve, that will let all the

* It is very difficult to convey my ideas of the quality of the stones to the reader, for want of something to measure or compare their degree of porosity or closeness, hardness or sofiness with. The knowledge of these different qualities is only to be attained by practice and experience; but I may observe, that there is no need of any pores in the stone to be larger in diameter than the length of a grain of wheat, for whatever they are larger, is so much loss of the face, because it is the edges that do the grinding; therefore, all large pores in stones are a disadvantage. The greater the number of pores in the stone, (so as to leave a sufficient quantity of touching surfaces, to reduce the flour to a sufficient degree of fineness) the better.

Mill-stone makers ought to be acquainted with the true principles on which grinding is performed, and with the art of manufacturing grain into flour, that they may be judges of the quality of the stones suitable to the quality of the wheat, of different parts of the country; also, of the best manner of disposing of the different pieces of stone, of different qualities, in the same mill-stone, according to the office of the several parts, from the centre to the verge of the stone. See art. 104.

Mill stones are generally but very carelessly and slightly made, whereas, they should be made with the greatest care and to the greatest nicety. The runner must be balanced exactly on its centre, and every corresponding opposite part of it should be of equal weight, or else the spindle will not keep tight in the bush: (see art. 107.) and if it is to be hung on a balance ryne, it should be put in at the formation of the stone, which should be nicely balanced thereon.

But above all, the quality of the stone should be most attended to, that no piece of an unsuitable quality for the rest, be put in; it being known to most experienced millers, that they had better give a high price for an extraordinary good pair, than to have an indifferent pair for nothing.

meal through, but none of the bran: but by this we cannot separate the different qualities of flour.

3. We provide as many sieves of the different degrees of fineness, as we intend to make different qualities of flour; and which, for distinction, we name—Superfine, Middlings, and Carnel.

The superfine sieve, of meshes so fine as to let through the superfine flour, but none of the middlings: the middlings' sieve, so fine as to let the middlings pass through, but none of the carnel: the carnel sieve, so fine as to let none of the shorts or bran pass through.

Now it is evident, that if we would continue the operation long enough, with each sieve, beginning with the superfine, that we might effect a complete separation.* But if we do not continue the operation a sufficient length of time, with each sieve, the separation will not be complete. For part of the superfine will be left, and will pass through with the middlings, and part of the middlings with the carnel, and part of the carnel with the shorts; and this would be a laborious and tedious work, if performed by the hand.

To facilitate this business, many have been the improvements; amongst which the circular sieve, or bolting-reel, is one of the foremost; and which was, at first, turned and fed by hand; though afterwards contrived to be turned by water.

But many have been the errors in the application of this machine, either by having the cloths too coarse, by which means the middlings and small pieces of bran will pass through with the superfine flour, and part of the carnel with the middlings: or by having the cloths too short, when they are fine enough, so that the operation cannot be continued a sufficient time to take all the superfine out, before it reaches the middlings' cloth, and all the middlings, before it reaches the carnel cloth.

The late improvements made on bolting, seem to be wholly as follows, viz.

* This method I have been informed is practised in England; they have several bolting cloths of different degrees of fineness for the same reel. They first put on the fine one, and pass the meal through, which takes out the superfine flour; they then take off the superfine cloth, and put on the next degree of fineness, which takes out the common fine flour; and so on through the different degrees, the cloths having drawing-strings at each end for drawing the ends close.

1. By using finer cloths—but they were found to clog, or choke up, when put on small reels of 22 inches diameter.

2. By enlarging the diameter of the reels to $27\frac{1}{2}$ inches, which gives the meal greater distance to fall, and causes it to strike harder against the cloth, which keeps it open.

3. By lengthening the cloths, that the operation may be continued a sufficient length of time.

4. By bolting a greater part of the flour over again, than was done formerly.

The meal, as it is ground, must be hoisted to the meal-loft, where it is spread thin, and often stirred, that it may cool and dry, to prepare it for bolting. After it is bolted, the tail-flour, or that part of the superfine that falls last, and which is too full of specks of bran to pass for superfine flour, is to be hoisted up again, and mixed with the ground meal, to be bolted over again. This hoisting, spreading, mixing, and attending the bolting hoppers, in merchant-mills, creates a great deal of hard labour, if done by hand; and is never completely done at last: but all this, and much more of the labour of mills, can now be done by machinery, moved by water. See part. 3.

Of Inspecting Flour.

The miller must by some means attain a knowledge of the standard quality, passable in the markets.

He holds a clean piece of board under the bolt, moving it from head to tail, so as to catch a proportional quantity all the way, as far as is taken for superfine: then, having smoothed it well, by pressing an even surface on it, to make the specks and colour more plainly appear; if it be not good enough, turn a little more of the tail to to be bolted over.

If the flour appears darker than expected, from the quality of the grain, it shows the grinding to be high, and bolting too near; because the finer the flour, the whiter its colour.*

* This appears reasonable, when we consider, that many dark coloured and transparent substances (while in a solid state) when pulverised, become white, and their whiteness is proportionate to the degree of pulverisation; for instance, salt, alum, and many kinds of stone, and particularly slate.—Ice pulverised is as white as snow, transparent wheat makes the whitest flour.

But this mode requires good light; therefore, the best way is for the miller to observe to what degree of poorness he may reduce his tail flour, or middlings, so as to be safe; by which he may judge with much more safety in the night. But the quality of the tail flour, middlings, &c. will greatly vary in different mills; for those that have the late improvements for bolting over the tail flour, grinding over the middlings, &c. can make nearly all into superfine.

Whereas, those that have them not—the quality that remains next to superfine, is common, or fine flour; then rich middlings, ship-stuff, &c. Those who have experience will conceive the difference in the profits. If the flour feels soft, dead, and oily, yet white, it shows the stones to have been dull, and too much pressure used. If it appear lively, yet dark coloured, and too full of very fine specks, it shows the stones to have been too rough, sharp, and that it was ground high and bolted too close.

CHAPTER VII.

Directions for keeping the Mill, and the business of it, in good order.

ART. 116.

THE DUTY OF THE MILLER.

THE mill is supposed to be completely finished for merchant work, on the new plan; supplied with a stock of grain, flour casks, nails, brushes, picks, shovels, scales, weights, &c. when the millers enter on their duty.

If there be two of them capable of standing watch, or taking charge of the mill, the time is generally divided as follows: In the day time they both attend to business, but one of them has the chief direction: The night is divided into two watches, the first of which ends at one o'clock in the morning; when the master miller should enter on his watch, and continue till morning; that he may be ready to direct other hands to their business early. The first thing he should do, when his watch begins, is to see whether the stones are grinding, and the cloths bolting, well.

And 2dly, to review all the moving gudgeons of the mill, to see whether any of them want grease, &c. that he may know what care may be necessary for them during his watch; for want of this the gudgeons often run dry, and heat, which brings on heavy losses of time and repairs; for when they heat, they get a little loose, and the stones they run on crack, after which they cannot be kept cool. He should also see what quantity of grain is over the stones, and if there be not enough to supply them till morning, set the cleaning machines in motion.

All things being set right, his duty is very easy—he has only to see the machinery, the grinding, and bolting, once in an hour; he has therefore plenty of time to amuse himself in reading, &c. rather than going to sleep, which is not safe.

Early in the morning, all the floors should be swept, and the flour dust collected. The casks nailed, weighed, marked and branded, and the packing began, that it may be completed in the forepart of the day; by this means, should any unforeseen thing occur, there will be spare time. Besides, to leave the packing till the afternoon, is a lazy practice, and keeps the business out of order.

When the stones are to be sharpened, every thing necessary should be prepared before the mill is stopped, (especially if there be but one pair of stones to a water-wheel) that as little time as possible may be lost: the picks made right sharp, not less than 12 in number. Things being ready, take up the stone; set one hand to each, and dress them as soon as possible, that they may be set to work again; not forgetting to grease the gears, and spindle foot.

In the after part of the day, a sufficient quantity of grain is cleaned down, to supply the stones the whole night; because it is best to have nothing to do in the night, more than to attend to the grinding, bolting, gudgeons, &c.

ART. 117.

PECULIAR ACCIDENTS BY WHICH MILLS ARE SUBJECT TO CATCH FIRE.

1. There being many moving parts in a mill, if any piece of timber fall, and lay on any moving wheel, or

shaft, and the velocity and pressure be great, it will generate fire, and perhaps consume the mill.

2. Many people use wooden candlesticks, that may be set on a cask, bench, or the floor, and forgetting them, the candle burns down, sets the stick, cask, &c. on fire, which perhaps may not be seen until the mill is in a flame.

3. Careless millers sometimes stick a candle to a cask, or post, and forget it, until it burns a hole in the post, or sets the cask on fire.

4. Great quantities of grain sometimes bend the floor so as to press the head blocks against the top of the upright shafts, and generate fire: (unless the head blocks have room to rise as the floor settles) mill-wrights should consider this, and be careful to guard against it as they build.

5. Branding irons, carelessly laid down, when hot, and left, might set something on fire.

6. I have heard of bran falling from the tail of a bolt, round a shaft, the friction of which burnt the shaft off.

7. The foot of the mill-stone spindle, and gudgeons, frequently heat, and set the bridge-tree or shaft on fire. It is probable, that from such causes mills have taken fire, when no person could discover how.

ART. 118.

OBSERVATIONS ON IMPROVING OF MILL SEATS.

I may end this part with a few observations on improving mill-seats. The improving of a mill-seat at 1000*l.* expense, is an undertaking worthy of mature deliberation, as wrong steps may increase it to 1100*l.* and the improvement be incomplete: whereas, right steps may reduce it to 900*l.* and perfect them.

Strange as it may appear, yet it is a real fact, that those who have least experience in the milling business, generally build the best and completest mills. The reasons are evident—

The experienced man is bound to old systems; he relies on his own judgment in laying all his plans; whereas,

The unexperienced man, being conscious of his deficiency, is at liberty; perfectly free from all prejudice, to call on all his experienced friends, and to collect all the improvements that are extant.

A merchant who knows but little of the miller's art, or of the structure or mechanism of mills, is naturally led to the following steps, viz.

He calls several of the most experienced millers and mill-wrights, to view the seat separately, and point out the spot for the mill-house, dam, &c. and notes their reasonings in favour of their opinion. The first perhaps fixes on a pretty level spot for the mill-house, and a certain rock, that nature seems to have prepared, to support the breast of the dam, and an easy place to dig the race, mill-seat, &c.

The second passes by these places without noticing them; explores the stream to the boundary line; fixes on another place, the only one he thinks appointed by nature for building a lasting dam, the foundation a solid rock, that cannot be undermined by the tumbling water; fixing on a rugged spot for the seat of the house: assigning for his reasons, that the whole fall must be taken in, that all may be right at a future day. He is then informed of the opinion of the other, against which he gives substantial reasons.

The mill-wright, carpenter and mason, that are to undertake the building, are now called together, to view the seat, fix on the spot for the house, dam, &c. After their opinion and reasons are heard, they are informed of the opinion and reasons of the others, all are joined together, and the places are fixed on. They are then desired to make out a complete draught of the plan for the house, &c. and to spare no pains to plan all for the best; but alter and improve on paper, till all appear to meet right, in the simplest and most convenient manner; (a week may be thus well spent) making out complete bills of every piece of timber, quantity of boards, stone, lime, &c. bill of iron work, number of wheels, their diameters, number of cogs, &c. &c. in the whole work. Each person can then make out his charge, and the costs can be counted nearly. Every species of materials may be contracted for, to be delivered in due time: then the work goes on regularly without disappointment, and when done, the improvements are complete, and 100*l.* out of 1000*l.* at least saved by such steps.

PART V.

THE

PRACTICAL MILL-WRIGHT;

CONTAINING

INSTRUCTIONS FOR BUILDING MILLS,

WITH

ALL THEIR PROPORTIONS;

SUITABLE

TO ALL FALLS OF FROM THREE TO THIRTY-SIX FEET.

Received from Thomas Ellicott,

Mill-Wright.

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ART. 1. Of undershot mills—directions for laying on the water.
Art. 2. Draught of a forebay, with directions for making them durable.
Art. 3. Principles and practical experiments, to determine the proper motion for undershot wheels.
A table for gearing undershot wheels, suited to all falls, from 3 to 20 feet.
Art. 4. Of breast mills, with directions for proportioning and gearing them, to give the stone the right motion.
Art. 5. Of pitch-back mills, do. do.
Art. 6. Of overshot mills, and their dimensions.
Art. 7. Of the proper motion for overshot mills.
Art. 8. Of gearing the water-wheel to the mill-stones, to give them the proper motion.
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TO THE READER.

I BEING requested by Oliver Evans, to assist him in completing his book, entitled, The Young Mill-wright and Miller's Guide, have thought proper to give the reader a short history of the rise and progress of merchant mills, towards their present state of perfection, since the beginning of my time.

It is now upwards of 38 years since I first began mill-wrighting: I followed it very constantly for about ten years, making it my particular study. Several of my brothers being also mill-wrights, we kept in company, and were often called to different parts of this and the adjacent states, to build mills of the first rates, in their day. Some of them entered into the manufacturing line; but I continued at mill-wrighting, and other business connected therewith; such as rolling-screens, and fans, and making them to go by water, in merchant and grist-mills; also farmer's fans, for cleaning grain; being one of* the first, I believe, that made these

* Mr. Ellicott observed that he was sorry the words (one of) had been left out, therefore they were put in by Mr. Evans.

things in America: but for several years past, have done but little else than build mills, or draught to build by.

When I first began the business, mills were at a low ebb in this country; neither burr-stones, nor rolling-screens being used; and but few of the best merchant mills had a fan. Many carried the meal on their backs, and bolted it by hand, even for merchant work; and I have frequently heard, that a little before my beginning the business, it had been customary, in many instances, to have the bolting mill some distance from the grinding mill, and there bolted by hand. It was counted extraordinary when they got their bolting to go by water: after this, fans by hand, and standing-screens, took place; then burr-stones, rolling-screens, and superfine bolting cloths, with a number of other improvements. Some of the latest are, the elevators, hopper-boys, &c.; invented by Oliver Evans, late of Delaware, though now of Philadelphia.

Being very desirous to improve in the art of building mills, and manufacturing grain into flour, I have frequently went a considerable distance to see new improvements, and have often searched the book-stores in expectation of finding books that might instruct me, but never found any which was of use to me in that respect, more than to learn the ancient names of some parts of the mills; for although they had been wrote by men of considerable learning, in other respects; yet, as they

had never been mill-wrights themselves, they had neither practical, nor experimental knowledge to direct them in the work. For instance, see the mill-wright's table, in Ferguson's Lectures, page 79, where the cog-wheel is to have 127 cogs, about 15 1-2 feet diameter; trundle, 6 staves, and stones 6 feet: And in Imison's Introduction to Useful Knowledge, page 31, the water-wheel is to be 18 feet, cog-wheel 254 cogs, about 31 feet diameter, much higher than the water-wheel; staves in the trundle 6, and stones 4 1-2 feet. Besides, some have asserted, that water applied on an undershot wheel, will do 6 times as much as if applied on an overshot; others, that if applied on an overshot it will do 10 times as much as an undershot, the quantity and falls being equal; many other parts of their theories are equally wrong in practice. So that what knowledge I have gained, has been by steady attention to the improvements of our own country: I have wondered, that no person of practical knowledge in the art, has yet attempted to write a treatise on it, seeing it is a subject worthy attention, and such a book so much wanted. The manufacturing of our own country produce, in the most saving, expeditious, and best manner, I have thought, is a subject worthy the attention of the legislatures. Mills are often laid under heavy taxes, being supposed to be very profitable; but if all the spare wheat was to be shipped, where would the miller's profit be? But to return to the subject: I have often thought,

that if I could spare time, I would write a small treatise on mill-wrighting myself, (thinking it would be of much use to young mill-wrights,) but fearing I was not equal to the task, I was ready to give it up; but on further consideration, I called on Thomas Dobson, printer of the Encyclopedia, and asked him if he would accept of a small treatise on mill-wrighting; he said Oliver Evans had been there a few days before, and proposed such a work, which I thought would save me the trouble. But some time afterwards, the said Evans, applied to me, requesting my assistance in his undertaking; this I was the more willing to do, having built several mills with his additional improvements, and draughted several others; and without which improvements, I think a mill cannot now be said to be complete. By them the manufacture of grain into flour, is carried on by water with very little hand labour, and much less waste, either in small or large business. And I do believe, that taking a large quantity of wheat together, that we can make 2 or 3 lbs. more out of a bushel by the new, than by the old way, although it be equally well ground; because it is so much more completely bolted, and with less waste. In the old way, the wheat is weighed and carried up one or two pair of stairs, and thrown into garners; the bags often having holes in, it is spilt and trampled under foot; several pounds being frequently lost in receiving a small quantity; and when it is taken from these garners, and carried to the roll-

ing-screens, some is again wasted, and as it is ground, it is shoveled into tubs, a dust is raised, and some spilt and trampled on; it is then hoisted, and spread, and tossed about with shovels, over a large floor, raked and turned to cool, and shoveled up again, and put into the bolting hopper; all which occasions great labour, besides being spilt and trampled over the mill, which occasions a considerable waste. Besides these disadvantages, there are others in attending the bolting hoppers; being often let run empty, then filled too hard, so that they choke, which occasions the flour to be very unevenly bolted; sometimes too poor, and at other times too rich, which is a considerable loss; and when the flour is bolted, it is much finer at the head than the tail of the cloths; the fine goes through first, and has to be mixed by hand, with shovels or rakes; and this labour is often neglected or only half done; by this means, part of the flour will be condemned for being too poor, and the rest above the standard quality. The hoisting of the tail flour, mixing it with bran, by hand, and bolting it over, is attended with so much labour, that it is seldom done to perfection.

In the new way, all these inconveniences and disadvantages are completely provided against: See plate XXII; which is a representation of the machinery, as they are applied in the whole process of the manufacture, taking the grain from the ship or wagon, and passing it through the whole process by water, until it is completely manufactured into superfine flour. As they are applied

in a mill of my planning and draughting, now in actual practice, built on Occoquam river, in Virginia, with 3 water-wheels, and 6 pair of stones.

If the wheat comes by water to the mill in the ship Z, it is measured and poured into the hopper A, and thence conveyed into the elevator at B, which elevates it, and drops it into the conveyer C D, which conveys it along under the joists of the second floor, and drops it into the hopper garner at D, out of which it is conveyed into the main wheat elevator at E, which carries it up into the peak of the roof, and delivers it into the rolling-screen at F, which (in this plan) is above the collar beams, out of which it falls into the hopper G, thence into the short elevator at H, which conveys it up into the fan I, from whence it runs down slanting into the middle of the long conveyer at j, that runs towards both ends of the mill, and conveys the grain, as cleaned, into any garner KKK KKK, over all the stones, which is done by shifting a board under the fan to guide the grain to either side of the cog-wheel j, and although each of these garners should contain 2000 bushels of wheat, over each pair of stones, 12000 bushels in 6 garners, yet nearly all may be ground out without handling it, and feed the stones more even and regular than it is possible to do in the old way. As it is ground by the several pairs of stones, the meal falls into the meal conveyer at M M M, and is conveyed into the common meal elevator at N, which raises it to O, from thence runs down the hopper-boy at P, which spreads and cools it over

a circle of 10 or 15 feet diameter, and (if thought best) will raise over it, and form a heap two or three feet high, perhaps thirty barrels of flour or more at a time, which may be bolted down at pleasure. When it is bolting, the hopper-boy gathers it into the bolting hoppers at Q, and attends them more regularly than is ever done by hand. As it is bolted, the conveyer R, in the bottom of the superfine chest, conveys the superfine flour to a hole through the floor at S, into the packing chest, which mixes it completely. Out of the packing chest it is filled into the barrel at T, weighed in the scale U, packed at W by water, headed at X, and rolled to the door Y, then lowered down by a rope and windlas into the ship again at Z.

If the wheat comes to the mill by land, in the wagon 7, it is emptied from the bags into a spout that is in the wall, and it runs in the scale 8, which is large enough to hold a wagon load, and as it is weighed it is (by drawing a gate at bottom) let run into the garner D, out of which it is conveyed into the elevator at E, and so through the same process as before.

As much of the tail of the superfine reels 37 as we think will not pass inspection, we suffer to pass on into the short elevator, (by shutting the gates at the bottom of the conveyer next the elevator, and opening one further towards the other end.) The rubblings, which fall at the tail of said reels, is also hoisted into the bolting hoppers of

the sifting reel 39, which is covered with a fine cloth, to take out all the fine flour dust, which will stick to the bran, in warm damp weather, and all that passes through it is conveyed by the conveyer 40, into the elevator 41, which elevates it so high that it will run freely into the hopper-boy at O, and is bolted over again with the ground meal. The rubblings that fall at the tail of the sifting reel 39, fall into the hopper of the middlings' reel 42; and the bran falls at the tail into the lower story. Thus you have it in your power either by day or night, without any hand labour except to shift the sliders, or some such trifle, to make your flour to suit the standard quality; and the most superfine possible made out of the grain, and finished complete at one operation.

These improvements are a curiosity worthy the notice of the philosopher and statesman, to see with what harmony the whole machinery works in all their different operations.

But to conclude, agreeably to request I attempt to show the method of making and putting water on the several kinds of water-wheels commonly used, with their dimensions, &c. suited to falls and heads from 3 to 36 feet; and have calculated tables for gearing them to mill-stones; and made draughts* of several water-wheels with their forebays and manner of putting on the water, &c.

THOMAS ELLICOTT.

* All my draughts are taken from a scale of 8 feet to an inch, except pl. V. which is 4 feet to an inch.

THE

PRACTICAL MILL-WRIGHT.

ART. 1.

OF UNDERSHOT MILLS.

FIG. 1, plate XIII, represents an undershot wheel 18 feet diameter, with 3 feet total head and fall. It should be 2 feet wide for every foot the mill-stones are in diameter; that is, 8 feet between the shrouds for a 4 feet, and 10 feet wide for a 5 feet stone. It should have three sets of arms and shrouds, on account of its great width. Its shaft should be at least 26 inches diameter. It requires 12 arms, 18 feet long, 3½ inches thick, by 9 wide; and 24 shrouds, 7½ feet long, 10 inches deep, by 3 thick, and 32 floats 15 inches wide. Note, it may be geared the same as an overshot wheel, of equal diameter. Fig. 2 represents the forebay, with its sills, posts, sluice and fall: I have in this case allowed 1 foot fall and 2 feet head.

Fig. 3 represents an undershot wheel, 18 feet diameter, with 7 feet head and fall. It should be as wide between the shrouds as the stone is in diameter. Its shaft should be 2 feet diameter. Requires 8 arms 18 feet long, 3¼ of an inch thick, by 9 wide. And 16 shrouds, 7½ feet long, 10 inches deep, by 3 thick. Note, it may be geared the same as an overshot wheel 13 feet diameter, because their revolutions per minute will be nearly equal.

Fig. 4 represents the forebay, sluice, and fall, the head and fall about equal.

Fig. 5 represents an undershot wheel, 12 feet diameter, with 15 feet total head and fall. It should be 6 inches wide for every foot the stone is in diameter. Its shaft 20 inches diameter. Requires 6 arms 12 feet long, 3 by 8 inches; and 12 shrouds, 6½ feet long, 2½ inches thick, and 8 deep. It suits well to be geared to a 5 feet stone with single gears, 60 cogs in the cog-wheel, and 16 rounds in the trundle; to a 4½ feet stone, with 62 cogs and 15 rounds; and, to a 4 feet stone, with 64 cogs and 14 rounds. These gears will do well till the fall is reduced to 12 feet, only the wheel must be less as the falls are less, so as to make the same number of revolutions in a minute; but this wheel requires more water than a breast-mill, with the same fall.

Fig. 6 is the forebay, gate, shute and fall. Forebays should be wide proportionable to the quantity of water they are to convey to the wheels; and should stand 8 or 10 feet in the bank, and be firmly joined, to prevent the water from breaking through; which it will certainly do, unless they be well secured.

ART. 2.

DIRECTIONS FOR MAKING FOREBAYS.

The best way that I know for making these kind of forebays, is shown in plate XVII, fig. 7. Make a number of solid frames, consisting of a sill, two posts, and a cap each; set them cross-wise, (as shown in the figure) 2½ or 3 feet apart; to these the plank are to be spiked, for there should be no sills lengthwise, as the water is apt to find its way along them. The frame at the head next the water, and one 6 or 8 feet downwards in the bank, should extend 4 or 5 feet on each side of the forebay in the bank; and be planked in front to prevent the water and vermin from working round. Both of the sills of these long frames should be well secured, by driving down plank edge to edge, like piles, along the upper side, from end to end.

The sills being settled on good foundations, the earth

or gravel must be rammed well on all sides, full to the top of the sills. Then lay the bottom with good sound plank, well jointed and spiked to the sills. Lay your shute, extending the upper end a little above the point of the gate when full drawn, to guide the water in a right direction to the wheel. Plank the head to its proper height, minding to leave a suitable sluice, to guide the water smoothly down. Fix the gate in an upright position—hang the wheel and finish it off ready for letting on the water.

A rack must be made to keep off the floating trash that would break the floats and buckets of undershot, breast, and pitch-back wheels, and injure the gates. See it at the head of forebay, fig. 7, plate XVII. This is done by setting a frame 3 feet in front of the forebay, and laying a sill 2 feet in front of it, for the bottom of the rack; in it the staves are put, made of laths, set edgewise with the stream, 2 inches apart, their upper ends nailed to the cap of the last frame, which causes them to lean down stream. The bottom of the race must be planked between the forebay and rack, to prevent the water from making a hole by tumbling through the rack when choked; and the sides be planked outside the posts to keep up the banks. This rack must be double as long as the forebay is wide, or else the water will not come fast enough through it to keep the head up; for the head is the spring of motion of an undershot mill.

ART. 3.

OF THE PRINCIPLE OF UNDERSHOT MILLS.

They differ from all others in principle, because the water loses all its force by the first stroke against the floats; and the time this force is spending, is in proportion to the difference of the velocities of the wheel and water, and the distance of the floats. Other mills have the weight of the water after the force of the head is spent, and will continue to move; but an undershot will stop as soon as the head is spent, as they depend not on

the weight. They should be geared so, that when the stone goes with a proper motion, they will not run too fast with the water, so as not to receive its force; nor too slow, so as to lose its power by rebounding and dashing over the buckets. This matter requires very close attention, and has puzzled our mechanical philosophers to find it out by theory. They give us for a rule, that the wheel must move just 1-3 the velocity of the water: perhaps this may suit where the head is not much higher than the float-boards, but I am fully convinced it will not suit high heads.

Experiments for determining the proper Motion for Undershot Wheels.

I drew a full sluice of water on an undershot wheel with 15 feet head and fall, and counted its revolutions per minute; then geared it to a mill-stone, set it to work properly, and again counted its revolutions, and the difference was not more than one-fourth slower. I believe, that if I had checked the motion of the wheel to be equal 1-3 the motion of the water, that the water would have rebounded and flew up to the shaft. Hence I conclude, that the motion of the water must not be checked by the wheel more than 1-3, nor less than 1-4; else it will lose in power; for although the wheel will carry a greater load with the slow, than swift motion, yet it will not produce so great effect, its motion being too slow. And again, if the motion be too swift, the load or resistance it will overcome will be so much less, that its effect will be lessened also. I conclude, that about 2-3 the velocity of the water is the proper motion for undershot wheels, the water will then spend all its force in the distance of two float-boards; notwithstanding the learned authors have asserted it to be but 1-3. To confute them, suppose the floats 12 inches, and the column of water striking them, 8 inches deep; then, if 2-3 of the motion of this column be checked, it must instantly become 24 inches deep, and rebound against the backs of the floats, and the wheel would be wallowing in this dead water; whereas, when 1-3 of its motion is checked, it becomes only 12 inches deep, and runs off from the wheel smooth and lively.

Directions for gearing Undershot Wheels, 18 *feet diameter, where the head is above* 3 *and under* 8 *feet, with double gears; counting the head from the point where the water strikes the floats.*

1. For 3 feet head and 18 feet wheel, see 18 feet wheel in the overshot table.
2. For 3 feet 8 inches head, see 17 feet wheel in said table.
3. For 4 feet 4 inches head, see 16 feet wheel in do.
4. For 5 feet head, see 15 feet wheel in do.
5. For 5 feet 8 inches head, see 14 feet wheel in do.
6. For 6 feet 4 inches head, see 13 feet wheel in do.
7. For 7 feet head, see 12 feet wheel in do.

The revolutions of the wheels will be nearly equal; therefore the gears may be the same.

The following table is calculated to suit for any sized stone, from 4 to 6 feet diameter; different sized water-wheels from 12 to 18 feet diameter, and different heads from 8 to 20 feet above the point it strikes the floats. And to make 5 feet stones revolve 88 times; 4 feet 6 inch stones 97 times; and 4 feet stones 106 times in a minute, when the water-wheel moves 2-3 the velocity of the striking water.

MILL-WRIGHT'S TABLE FOR UNDERSHOT MILLS—SINGLE GEARED.

Height of the head of water in feet.	Diameter of the water-wheel in feet.	Velocity of the water per minute in feet.	Velocity of the water-wheel per minute in feet	Revolutions of the water-wheel per minute.	Revolutions of the stone per minute.	Number of cogs in the cog-wheel.	Number of rounds in the trundle head.	Revolutions of the mill-stone for one of the water-wheels.	Diameter of the stones in feet.
8	12	1360	906	24	88	56	15	3 3-4	5
9	13	1448	965	23 1-2	88	58	15	3 7-8	5
10	14	1521	1014	23 1-7	88	58	15	3 6-7	5
11	15	1595	1061	22 3-4	88	58	15	3 3-4	5
12	16	1666	1111	22 1-4	88	58	15	3 7-8	5
13	16	1735	1157	23 1-7	88	60	16	3 3-4	5
14	16	1800	1200	24	88	59	16	3 2-3	5
15	16	1863	1242	24 4-5	88	60	17	3 1-2	5
16	16	1924	1283	25 2-3	88	59	17	3 3-8	5
17	17	1983	1322	25	88	62	17	3 3-4	5
18	17	2041	1361	25 2-3	88	62	17	3 3 8	5
19	18	2097	1398	25	88	62	17	3 3-4	5
20	18	2152	1435	25 1-2	88	60	17	3 3-8	5
1	2	3	4	5	6	7	8	9	10

Note that there is nearly 60 cogs in the cog-wheel, in the foregoing table, and 60 inches is the diameter of a 5 feet stone; therefore, it will do without sensible error, to put 1 cog more in the wheel for every inch that the stone is less than 60 inches diameter, down to 4 feet; the trundle head and water-wheel the same.

And for every 3 inches that the stone is larger than 60 inches in diameter, put 1 round more in the trundle, and the motion of the stone will be nearly right up to 6 feet diameter.

ART. 4.

OF BREAST-WHEELS.

Breast wheels differ but little in their structure or motion from overshots, excepting only, the water passes under instead of over them, and they must be wider in proportion as their fall is less.

Fig. 1, plate XIV, represents a low breast with 8 feet head and fall. It should be 9 inches wide for every foot of the diameter of the stone. Such wheels are generally 18 feet diameter; the number and dimensions of their parts being as follows: 8 arms 18 feet long, 3 1-4 by 9 inches; 16 shrouds 8 feet long, 2 1-2 by 9 inches; 56 buckets; and shaft, 2 feet diameter.

Fig. 2. shows the forebay, water-gate, and fall, and manner of striking on the water.

Fig. 3. is a middling breast-wheel 18 feet diameter, with 12 feet head and fall. It should be 8 inches wide for every foot the stone is in diameter.

Fig. 4. shows the forebay, gate and fall, and manner of striking on the water.

Fig. 5. and 6. is a high breast-wheel, 16 feet diameter, with 3 feet head in the forebay, and 10 feet fall. It should be 7 inches wide for every foot the stone is in diameter. The number and dimensions of its parts are, 6 arms 16 feet long, 3 1-4 by 9 inches; 12 shrouds 8 feet 6 inches long, 2½ by 8 or 9 inches deep, and 48 buckets.

ART. 5.

OF PITCH-BACK WHEELS.

Pitch-back wheels are constructed exactly similar to breast-wheels, only the water is struck on them higher. Fig. 1, plate XV, is a wheel 18 feet diameter, with 3 feet head in the penstock, and 16 feet fall below it. It should be 6 inches wide for every foot of the diameter of the stone.

Fig. 2 shows the trunk, penstock, gate, and fall, the gate sliding on the bottom of the penstock, and drawn by the lever A, turning on a roller. This wheel is much recommended by some mechanical philosophers, for the saving of water; but I do not join them in opinion, but think that an overshot with an equal head and fall, is fully equal in power; besides the saving of the expense of so high a wheel and fall, that are difficult to be kept in order.

ART. 6.

OF OVERSHOT WHEELS.

Overshot wheels receive their water on the top, being moved by its weight; and are much to be recommended where there is fall enough for them. Fig. 3 represents one 18 feet diameter, which should be about 6 inches wide for every foot the stone is in diameter. It should hang 8 or 9 inches clear of the tail water, because they draw it under them. The head in the penstock should be generally about 3 feet, which will spout the water about 1-3 faster than the wheel moves. Let the shute have about 3 inches fall, and direct the water into the wheel at the centre of its top.

I have calculated a table for gearing overshot wheels, which will equally well suit any of the others of equal diameter, that have equal heads above the point where the water strikes the wheel.

Dimensions of this wheel, 8 arms 18 feet long, 3 by 9 inches; 16 shrouds 7 feet 9 inches long, $2\frac{1}{2}$ by 7, or 8 inches; 56 buckets, and shaft, 24 inches diameter.

Fig. 4 represents the penstock and trunk, &c. the water being let on the wheel by drawing the gate G.

Fig. 1 and 2 plate XVI, represents a low overshot 12 feet diameter, which should be in width equal to the diameter of the stone. Its parts and dimensions are, 6 arms 12 feet long, $3\frac{1}{2}$ by 9 inches; 12 shrouds $6\frac{1}{2}$ feet long, $2\frac{1}{2}$ by 8 inches; shaft 22 inches diameter, and 30 buckets.

Fig. 3 represents a very high overshot 30 feet diameter, which should be $3\frac{1}{2}$ inches wide for every foot of the diameter of the stone. Its parts and dimensions are, 6 main arms, 30 feet long, $3\frac{1}{4}$ inches thick, 10 inches wide at the shaft, and 6 at the end; 12 short arms 14 feet long, of equal dimensions; which are framed into the main arms near the shaft, as in the figure; for if they were all put through the shaft, they would make it too weak. The shaft should be 27 inches diameter, the wheel being very heavy and bearing a great load. Such high wheels require but little water.

ART. 7.

OF THE MOTION OF OVERSHOT WHEELS.

After trying many experiments, I concluded that the circumference of overshot wheels geared to mill-stones, grinding to the best advantage, should move 550 feet in a minute; and that of the stones 1375 feet in the same time; that is, while the wheel moves 12, the stone moves 30 inches, in the proportion of 2 to 5.

Then, to find how often the wheel we propose to make will revolve in a minute, take the following steps: 1st, Find the circumference of the wheel by multiplying the diameter by 22, and dividing by 7, thus:

Suppose the diameter to be 16 feet, then 16 multiplied by 22, produces 352; which, divided by 7, quotes 50 2-7 for the circumference.

$$\begin{array}{r} 16 \\ 22 \\ \hline 32 \\ 32 \\ \hline 7)352 \\ \hline 50\ 2\text{-}7 \end{array}$$

By which we divide 550, the distance the wheel moves in a minute, and it quotes 11, for the revolutions of the wheel per minute, casting off the fraction 2-7, it being small.

$$\begin{array}{r} 5|0)55|0 \\ \hline 11 \text{ times.} \end{array}$$

To find the revolutions of the stone per minute, 4 feet 6 inches (or 54 inches) diameter, multiply 54 inches by 22, and divide by 7, and it quotes 169 5-7 (say 170) inches, the circumference of the stone.

$$\begin{array}{r} 54 \\ 22 \\ \hline 108 \\ 108 \\ \hline 7)1188 \\ \hline 169\ 5\text{-}7 \end{array}$$

By which divide 1375 feet, or 16500 inches, the distance the skirt of the stone should move in a minute, and it quotes 97; the revolutions of a stone per minute, 4 1-2 feet diameter.

$$\begin{array}{r} 1375 \\ 12 \\ \hline 17|0)1650|0(97 \\ 153 \\ \hline 120 \\ 119 \\ \hline 1 \end{array}$$

To find how often the stone revolves for once of the water wheel, divide 97, the revolutions of the stone, by 11, the revolutions of the wheel, and it quotes 8 9-11, (say 9 times.)

$$\begin{array}{r} 11)97(8\ 9\text{-}11 \\ 88 \\ \hline 9 \end{array}$$

ART. 8.

OF GEARING.

Now if the mill was to be single geared, 99 cogs and 11 rounds, would give the stone the right motion, but the cog-wheel would be too large, and trundle too small, therefore it must be double geared.

Suppose we choose 66 cogs in the big cog-wheel and 48 in the little one, and 25 rounds in the wallower, and 15 in the trundle.

Then, to find the revolutions of the stone for one of the water-wheel, multiply the cog-wheels together, and the wallower and trundle together, and divide one product by the other, and it will quote the answer, $8\frac{168}{375}$, not quite $8\frac{1}{2}$ revolutions instead of 9.

```
      25
      15
     125
     25
     375

      66
      48
     528
    264
375)3168(8 168-375
    3000
     168
```

Therefore we must make another proposition—Considering which of the wheels we had best alter, and wishing not to alter the big cog-wheel nor trundle, we put one round less in the wallower, and two cogs more in the little cog-wheel, and multiplying and dividing as before, we find the stone will turn 9 1-6 times for once of the water-wheel, which is as near as we can get. The mill now stands thus, a 16 foot overshot wheel, that will revolve 11 times in a minute, geared to a stone 4 1-2 feet diameter; the big cog-wheel 66 cogs, 4 12 inches from centre to centre of the cogs; (which we call the pitch of the gear) little cog-wheel 50 cogs $4\frac{1}{4}$ pitch; wallower 24 rounds, $4\frac{1}{2}$ pitch, and trundle 15 rounds, $4\frac{1}{4}$ inches pitch.

ART. 9.

RULES FOR FINDING THE DIAMETER OF THE PITCH CIRCLES.

To find the diameter of the pitch circle, that the cogs stand in, multiply the number of cogs by the pitch, which gives the circumference; which, multiplied by 7, and divided by 22, gives the diameter in inches; which, divided by 12, reduces it to feet and inches thus:

```
     66
      4½
    264
     33
    297
      7
22)2079(94½ in.
   198
     99
     88
     11
```

For the cog-wheel of 66 cogs, $4\frac{1}{2}$ pitch, we find to be 7 feet 10 11-22 inches, the diameter of the pitch circle; to which I add 8 inches, for the outside of the cogs, makes 8 feet $6\frac{1}{2}$ inches, the diameter from out to out.

By the same rules I find the diameters of the pitch circles of the other wheels, to be as follows, viz.

	ft.	in.	
Little cog-wheel 50 cogs, $4\frac{1}{2}$ inches pitch,	5	$7\frac{1}{2}$	10-22 p. cir.
I add for the outside of the circle,		$7\frac{1}{2}$	
Total diameter from out to out	6	3	
Wallower 24 rounds $4\frac{1}{4}$ inches pitch,	2	11	3-4 4-22
Add for outsides,	0	3	18-22 do.
Total diameter from the outsides,	3	3	
Trundle head 15 rounds $4\frac{1}{2}$ inch pitch,	1	$8\frac{1}{4}$	3-22 do.
Add for outsides,		$2\frac{1}{2}$	19-22
Total diameter for the outsides,	1	11	

Thus we have completed the calculations for one mill, with a 16 feet overshot water-wheel, and stones $4\frac{1}{2}$ feet diameter. By the same rules we may calculate for wheels of all sizes from 12 to 30 feet, and stones from 4 to 6 feet diameter, and may form tables that may be of great use to many, even to master-workmen that understand calculating well in despatching of business, in laying out work for their apprentices and other hands, getting out timber, &c. but more especially to those who are not learned in arithmetic sufficient to calculate, I being from long experience highly sensible of the need of such a table, have therefore undertaken the arduous task.

MILL-WRIGHTS' TABLES,

Calculated to suit overshot water-wheels with suitable heads above them, of all sizes from 12 to 30 feet diameter, the velocity of their circumferences being about 550 feet per minute, showing the number of cogs and rounds in all the wheels, double gear, to give the circumference of the stone a velocity of 1375 feet per minute, also the diameter of their pitch circles, the diameter of the outsides, and revolutions of the water-wheel and stones per minute.

For particulars see what is written over the head of each table. Table I, is to suit a 4 feet stone, table II, a $4\frac{1}{2}$, table III, a 5 feet, and table IV, a $5\frac{1}{2}$ feet stone.

N. B. If the stones should be an inch or two bigger or less than those above described, make use of the table that comes nearest to it, and likewise for the water-wheels. For further particulars see draughting mills.

Use of the following Tables.

Having levelled your mill-seat and found the total fall, after making due allowances for the fall in the races, and below the wheel, suppose there is 21 feet 9 inches, and the mill-stones are 4 feet diameter, then look in table I, (which is for 4 feet stones) column 2, for the fall that is nearest yours, and you find it in the 7th example: and against it in column 8, is the head proper to be above the wheel 3 feet, in column 4 is 18 feet, for the diameter of the wheel, &c. for all the proportions of the gears to make a steady moving mill, the stones to revolve 106 times in a minute.*

* The following tables are calculated to give the stones the revolution per minute mentioned in them, as near as any suitable number of cogs and rounds would permit, which motion I find is 8 or 10 revolutions per minute slower than proposed by Evans in his table;—his motion may do best in cases where there is plenty of power and steady work on one kind of grain; but in country mills, where they are continually changing from one kind to another, and often starting and stopping, I presume a slow motion will work most regular. His table being calculated for only one size of mill-stones, and mine for four, if any choose his motion, look for the width of the water-wheel, number of cogs, and rounds and size of the wheels to suit them, in the next example following, keeping to my table in other respects, and you will have his motion nearly.

TABLE I. For Overshot Mills with Stones 4 feet Diameter, to revolve 106 times in a minute, pitch of the gear of great cog wheel and wallowers 4½ inches, and of lesser cog wheel and trundle 4¼ inches.

No. of examples.	Total falls of water from the top of that in the penstock to that in the tail-race.	Different heads of water above the water-wheels.	Diameters of water-wheels from out to out.	Widths of water-wheels in the clear.	No. of cogs in the great and lesser cog-wheels.	Diameters of pitch circles of great and lesser wheels.	Diameters of cog-wheels from out to out.	No. of rounds in the wallowers and trundles.	Diameters of pitch circles in wallowers and trundles.	Total diameters of wallowers and trundles.	Revolutions of great wheel per minute, nearly.
	ft. in.	f. i.	feet.	f. i.		f. i.	f. in.		f. i.	f. i.	
1	15,3	2,6	12	3,0	66	7,10 5	8,6.5	25	2,11.75	3,3	13
					48	5,4 87	6,0.5	15	1,8.33	1,11.33	
2	16,4	2,7	13	2,10	69	8,2.33	8,10.33	25	2,11 75	3,3	12.5
					48	5,4 87	6,0.5	15	1,8.33	1,11.33	
3	17,5	2,8	14	2,8	69	8,2.33	8,10 33	26	3,1 25	3,5.25	12
					48	5,4.87	6,0.5	15	1,8.33	1,11.33	
4	18,6	2,9	15	2,6	69	8,2.33	8,10.33	25	2,11.75	3,3	11.5
					50	5,7.5	6,3	15	1,8.33	1,11.33	
5	19,7	2,10	16	2,4	72	8,7.25	9,3	26	3,1.25	3,5.25	11
					52	5,10.33	6,6	15	1,8 33	1,11.33	
6	20,8	2,11	17	2,3	72	8,7.25	9,3	25	2,11.75	3,3	10.5
					52	5,10.33	6,6	14	1,7	1,10	
7	21,9	3,0	18	2,2	72	8,7.25	9,3	24	2,10 33	3,1.5	10
					52	5,10.33	6,6	14	1,7	1,10	
8	22,10	3,1	19	2,1	75	8,11.33	9,7.33	24	2,10.33	3,1.5	9.66
					52	5,10.33	6,6	14	1,7	1,10	
9	23,11	3,2	20	2,0	75	8,11.33	9,7.33	23	2,9	3,0	9.25
					52	5,10.33	6,6	14	1,7	1,10	
10	25,1	3,4	21	1,11	78	9,3.5	9,11.5	24	2,10.33	3,1.5	8.87
					52	5,10.33	6,6	14	1,7	1,10	
11	26,3	3,6	22	1,10	78	9,3.5	9,11 5	23	2,9	3,0	8.5
					52	5,10.33	6,6	14	1,7	1,10	
12	27,5	3,8	23	1,9	78	9,3.5	9,11.5	23	2,9	3,0	8.25
					54	6,1	6,8.5	14	1,7	1,10	
13	28,7	3,10	24	1,8	81	9,8	10,4	23	2,9	3,0	8
					54	6,1	6,8.5	14	1,7	1,10	
14	29,9	4,0	25	1,7	81	9,8	10,4	23	2,9	3,0	7.75
					56	6,3 75	6,11.25	14	1,7	1,10	
15	30,11	4,2	26	1,6	84	10,0.25	10,8 25	23	2,9	3,0	7.5
					56	6,3.75	6,11.25	14	1,7	1,10	
16	32,1	4,4	27	1,5	84	10,0 25	10,8.25	23	2,9	3,0	6.75
					58	6,6 25	7,1 75	14	1,7	1,10	
17	33,3	4,6	28	1,4	84	10,0.25	10,8.25	23	2,9	3,0	6.66
					56	6,3 75	6,11.25	13	1,5.25	1,8.25	
18	34,6	4,9	29	1,3	84	10,0.25	10,8.25	22	2,7.5	2,10.5	6.5
					56	6,3.75	6,11.25	13	1.5.25	1,8.25	
19	35,9	5,9	30	1,2	87	10,5	11,1	22	2,7.5	2,10 5	6.25
					56	6.3 75	6,11 25	13	1,5 25	1,8.25	

TABLE II. For Overshot Mills with Stones 4 feet 6 inches Diameter, to revolve 99 times in a minute, pitch of the gears 4½ inches and 4¼ inches.

No. of examples.	Total falls of water from the top of that in the penstock to that in the tail-race.	Different head of water above the water wheel.	Diameters of water wheels from out to out.	Widths of water wheels in the clear.	No. of cogs in the great and lesser cog-wheels.	Diameters of pitch circles of great and lesser cog-wheels.	Diameters of cog-wheels from out to out.	No. of rounds in wallowers and trundles.	Diameters of pitch circles in wallowers and trundles.	Total diameters of wallowers and trundles.	Revolutions of the great wheel per minute, nearly.
	ft. in.	ft. in.	feet	ft. in.		ft. in.	ft in.		ft. in.	ft. in.	
1	15,3	2,6	12	3,6	66 48	7,10.5 5,4.87	8,6.5 6,0 5	26 15	3,1.25 1,8 33	3,4.25 1,11.33	13
2	16,4	2,7	13	3,4	66 48	7,10 5 5,4.87	8,6.5 6,0.5	25 15	2,11.75 1,8.33	3,3 1,11.33	12.5
3	17,5	2,8	14	3,2	69 48	8,2.33 5,4 87	8,10 33 6,0.5	26 15	3,1.25 1,8 33	3,4.25 1,11.33	12
4	18,6	2,9	15	3,0	69 48	8,2.33 5,4 87	8,10.33 6,0.5	25 15	2,11 75 1,8 33	3,3 1,11.5	11 5
5	19,7	2,10	16	2,10	69 50	8,2.33 5,7.87	8,10.33 6,3	25 15	2,11.75 1,8.33	3,3 1,11.5	11
6	20,8	2,11	17	2,8	72 52	8,7.25 5,10,33	9,3 6,6	26 15	3,1.25 1,8.33	3,4.25 1,11 5	10 5
7	21,9	3,0	18	2,6	72 52	8,7.25 5,10.33	9,3 6,6	25 14	2,11.75 1,7	3,3 1,11.5	10
8	22,10	3,1	19	2,4	72 52	8,7.25 5,10.33	9,3 6,6	24 14	2,10.33 1,7	3,2 5 1,11 5	9.5
9	23,11	3,2	20	2,3	75 52	8,11.33 5,10 33	9.7.33 6,6	24 14	2,10.33 1,7	3,2.5 1,11.5	9
10	25,1	3,4	21	2,2	75 52	8,11.33 5,10.33	9,7.33 6,6	23 14	2,9 1,7	3,0 1,11 5	8.75
11	26,3	3,6	22	2,1	78 52	9,3.5 5,10.33	9,11.5 6,6	24 14	2,10.33 1,7	3,2.5 1,11.5	8.75
12	27,5	3,8	23	2,0	78 52	9,3-5 5,10.33	9,11.5 6,6	23 14	2,9 1,7	3,0 1,11.5	8.25
13	28,7	3,10	24	1,11	78 54	9,3.5 6,1	9,11.5 6,8.5	23 14	2,9 1,7	3,0 1,11.5	8
14	29,9	4,0	25	1,10	81 54	9,8 6,1	10,4 6,8.5	23 14	2,9 1,7	3,0 1,11.5	7.75
15	30,11	4,2	26	1,9	81 56	9,8 6,3-25	10,4 6,11.25	23 14	2,9 1.7	3,0 1,11.5	7 5
16	32,1	4,4	27	1,8	84 56	10,0 25 6,3-25	10,8.25 6,11.25	23 14	2,9 1,7	3,0 1,11.5	6 75
17	33,3	4,6	28	1,6	84 58	10,0-25 6,6.25	10,8 25 7,1 25	23 14	2,9 1,7	3,0 1,11 5	6.66
18	34,6	4,9	29	1,5	84 56	10,0.25 6,3-25	10,8.25 6,11 25	23 13	2,9 1.5.25	3,0 1,8 25	6 5
19	35,9	5,0	30	1,4	84 56	10,0 75 6,3.25	10,8.25 6,11.25	22 13	2,7.5 1,5 25	2,10.5 1,8 25	6 25

TABLE III. Stones 5 feet Diameter, to revolve 86 times in a minute, the pitch of the gears $4\frac{1}{2}$ and $4\frac{1}{4}$ inches.

No. of examples	Total falls of water from the top of that in the penstock to that in the tail-race.	Different head of water above the water wheel.	Diameters of water wheels from out to out.	Widths of water wheels in the clear.	No. of cogs in the great and lesser cog-wheels.	Diameters of pitch circles of great and lesser cog-wheels.	Diameters of cog-wheels from out to out.	No. of rounds in wallowers and trundles.	Diameters of pitch circles in wallowers and trundles.	Total diameters of wallowers and trundles.	Revolutions of the great wheel per minute, nearly.
	ft in.	ft in	feet	ft.in.		ft. in.	ft in.		ft. in.	ft. in.	
1	15,3	2,6	12	4,0	63 48	7,6.12 5,4.87	8.2.12 6,0.5	26 16	3,1.25 1,9 66	3,4.25 2,4.25	13
2	16,4	2,7	13	3,10	66 48	7,10.5 5,4.87	8,6.5 6,0.5	26 16	3,1.25 1,9.66	3,4.25 2,4.25	12.5
3	17,5	2,8	14	3,8	66 48	7,10.5 5,4.87	8,6.5 6,0.5	25 15	2,11.75 1,8 33	3,3 1,11.33	12
4	18,6	2,9	15	3,6	69 48	8,2.33 5,4 87	8,10.33 6,0.5	26 15	3,1 25 1,8.33	3,4.25 1,11.33	11.5
5	19,7	2,10	16	3,4	69 48	8,2 33 5,4.87	8,10.33 6,0.5	25 15	2,11.75 1,8.33	3,3 1,11.5	11
6	20,8	2,11	17	3,2	69 50	8,2.33 5,7.5	8,10.33 6,3	25 15	2,11.75 1,8.33	3,3 1.11 5	10.5
7	21,9	3,0	18	3,0	72 52	8,7.25 5,10,33	9,3 6,6	26 15	3,1.25 1,8.33	3,4.25 1,11.33	10
8	22,10	3,1	19	2,10	72 52	8,7.25 5,10.33	9,3 6,6	25 14	2,11.75 1,7	3,3 1,11.5	9.66
9	23,11	3,2	20	2,8	72 52	8.7.25 5,10 33	9,3 6,6	24 14	2,10.33 1,7	3,2 5 1,11.5	9.25
10	25,1	3,4	21	2.6	75 52	8,11.33 5,10.33	9.7.33 6,6	24 14	2,10.33 1,7	3,2.5 1,11.5	8.87
11	26,3	3,6	22	2 5	75 52	8,11.33 5,10.33	9,7.33 6,6	23 14	2,9 1,7	3,0 1,11.5	8.5
12	27,5	3,8	23	2,4	78 52	9,3.5 5,10.33	9,11.5 6,6	24 14	2,10.33 1,7	3,2.33 1,11.5	8.25
13	28,7	3,10	24	2,3	78 52	9,3.5 5,10.33	9,11.5 6,6	23 14	2,9 1,7	3,0 1,11.5	8
14	29,9	4,0	25	2,2	78 54	9,3.5 6,1	9,11.5 6,8.5	23 14	2,9 1,7	3,0 1,11 5	7.75
15	30,11	4,2	26	2,0	81 54	9.8 6,1	10,4 6,8 5	23 14	2,9 1,7	3,0 1,11.5	7 5
16	32,1	4,4	27	1,11	81 56	9.8 6,3.25	10,4 6,11 25	23 14	2.9 1,7	3,0 1,11.5	6.33
17	33,3	4,6	28	1,9	84 56	10,0 25 6,3.25	10,8 25 6,11 25	23 14	2,9 1,7	3,0 1,11.5	6.66
18	34,6	4.9	29	1,7	84 58	10,0.25 6,6.25	10,8 25 7,1 25	23 14	2,9 1,7	3,0 1,11.5	6.25
19	35,9	5,0	30	1,6	84 56	10,0.25 6,3 25	10,8 25 6,11 25	23 13	2,9 1,5.25	3,0 1,8 25	6.25

TABLE IV. For Overshot Mills with Stones 5 feet 6 inches Diameter, to revolve 80 times in a minute, pitch of the gears $4\frac{3}{4}$ inches and $4\frac{1}{2}$ inches.

No. of examples.	Total falls of water from the top of that in the penstock to top of that in the tail-race.	Different heads of water above the water-wheels.	Diameters of water-wheels from out to out.	Widths of water-wheels in the clear.	No. of cogs in the great and lesser cog-wheels.	Diameters of pitch circles of great and lesser cog wheels	Diameters of cog-wheels from out to out.	No. of rounds in the wallowers and trundles.	Diameters of pitch circles in wallowers and trundles.	Total diameters of wallowers and trundles.	Revolutions of great wheel per minute, nearly.
	ft. in.	f. i.	feet.	f. i.		f. i.	f. in.		f. i.	f. i.	
1	15,3	2,6	12	4,6	60 48	7,6.75 5,8 75	8,2.75 6,4 25	26 16	3,3.25 1,11	3,6.25 2,2	13
2	16,4	2,7	13	4,4	63 48	7,11 12 5,8 75	8,7.12 6,4.25	26 16	3,3 25 1,11	3,6.25 2,2	12.5
3	17,5	2,8	14	4,2	66 48	8,3 75 5,8.75	8,11 75 6,4 25	26 16	3,3.25 1,11	3,6.25 2,2	12
4	18.6	2,9	15	4,0	66 48	8.3.75 5,8.75	8,11.75 6,4 25	26 15	3,3 25 1,9 5	3,6.25 2,0.5	11.5
5	19,7	2,10	16	3,10	69 48	8,8 33 5,8.75	9,4.33 6,4.25	26 15	3 3 25 1,9.5	3,6.25 2,0.5	11
6	20,8	2,11	17	3,8	69 48	8,8.33 5,8.75	9,4.33 6.4 25	25 15	3,1.75 1,9.5	3,4.75 2,0.5	10.5
7	21,9	3,0	18	3,6	69 50	8,8.33 5,11 5	9,4 33 6,2.5	25 15	3,1 75 1,9.5	3,4.75 2,0.5	9
8	22,10	3,1	19	3,4	72 52	9,0.75 6,2.5	9,8 75 6,10	26 14	3,3.25 1,8	3,6.25 1,11	9.66
9	23,11	3,2	20	3,2	72 52	9,0.75 6,2.5	9,8.75 6,10	25 14	3,1 75 1,8	3,4.75 1,11	9 25
10	25,1	3,4	21	3,0	72 52	9.0 75 6,2.5	9,8 75 6,10	24 14	3,0 75 1,8	3,3.75 1,11	8.12
11	26,3	3,6	22	2,10	75 52	9,5.33 6,2.5	10,1.33 6,10	23 14	3,0.75 1,8	3.3.75 1,11	8·5
12	27,5	3,8	23	2,8	75 52	9,5.33 6,2.5	10,1.33 6,10	23 14	2,10.75 1,8	3,1.75 1,11	8·25
13	28,7	3,10	24	2,6	78 52	9,10.5 6,2.5	10,6 6,10	24 14	3,0.75 1,8	3,3.75 1.11	8
14	29,9	4,0	25	2,4	78 52	9,10 5 6,2.5	10,6 6,10	23 14	2,10.75 1,8	3,1.75 1,11	7.75
15	30,11	4,2	26	2,2	78 54	9,10 5 6,5.33	10,6 7,1	23 14	2,10 75 1,8	3,1.75 1,11	7.5
16	32,1	4,4	27	2,0	81 54	10,2.5 6,5.33	10,10.5 7,1	23 14	2,10.75 1,8	3,1.75 1,11	6.75
17	33,3	4,6	28	1,11	81 56	10,2 5 6,8	10,10 5 7,3 5	23 14	2,10.75 1,8	3,1.75 1,11	6.66
18	34,6	4,9	29	1,10	84 56	10,7 6,8	11,3 7,3.5	23 14	2,10.75 1,8	3,1.75 1,11	6.5
19	35,9	5,0	30	1,9	84 58	10,7 6,11	11 3 7,6.5	23 14	2,10.75 1,8	3,1.75 1,11	6.25

ART. 10.

DIRECTIONS FOR CONSTRUCTING UNDERSHOT WHEELS, SUCH AS FIG. 1, PLATE XIII.

1. Dress the arms straight and square on all sides, and find the centre of each; divide each into 4 equal parts on the side square centre scribe, and gauge them from the upper side across each point, on both sides, 6 inches each way from the centre.

2. Set up a truckle or centre-post, for a centre to frame the wheel on, in a level place of ground, and set a stake to keep up each end of the arms level with the truckle, of convenient height to work on.

3. Lay the first arm with its centre on the centre of the truckle, and take a square notch out of the upper side 3-4 of its depth, wide enough to receive the 2d arm.

4. Make a square notch in the lower edge of the 2d arm, 1-4 of its depth, and lay it in the other, and they will joint standing square across each other.

5. Lay the 3d arm just equi-distant between the others, and scribe the lower arms by the side of the upper, and the lower edge of the upper by the sides of the lower arms. Then, take the upper arm off and strike the square scribes, taking out the lower half of the 3d arm, and the upper half of the lower arms, and fit and lay them together.

6. Lay the 4th arm on the others, and scribe as directed before; then take 3-4 of the lower edge of the 4 h arm, and 1-4 out of the upper edge of the others, and lay them together, and they will be locked together in the depth of one.

7. Make a sweep-staff with a gimblet hole for the centre at one end, which must be set by a gimblet in the centre of the arms. Measure from this hole half the diameter of the wheel, making a hole there, and another the depth of the shrouds towards the centre, making each edge of this sweep at the end next the shrouds, straight towards the centre hole, to scribe the ends of the shrouds by.

8. Circle both edges of the shrouds by the sweep,

dress them to width and thickness, lay out the laps 5 inches long, set a gauge to a little more than 1-3 their thickness, gauge all their ends for the laps from the outsides, cut them all out but the last, that it may be made a little longer, or shorter, as may suit to make the wheel the right diameter; sweep a circle on the arms to lay the shrouds to, while fitting them, put a small draw-pin in the middle of each lap, to draw the joints close, strike a true circle for both inside and outside the shrouds, and one 1 1-2 inch from the inside, where the arms are to be let in.

9. Divide the circle into 8 equal parts, coming as near the middle of each shroud as possible; strike a scribe across each to lay out the notch by, that is to be cut by 1½ inch deep, to let in the arm at the bottom of where it is to be forked to take in the remainder of the shroud. Strike a scribe on the arms with the same sweep that the stroke on the shrouds for the notches was struck with.

10. Scribe square down each side of the arms, at the bottom of where they are to be forked; make a gauge to fit the arms, so wide as just to take in the shrouds, and leave 1½ inch of wood outside of the mortise; bore 1 or 2 holes through each end of the arms to draw-pin the shrouds to the arms when hung; mark all the arms and shrouds to their places, and take them apart.

11. Fork the arms, put them together again, and put the shrouds into the arms; drawbore them, but not too much, which would be worse than too little; take the shrouds apart again, turn them the other side up, and draw the joints together with the pins, and lay out the notches for 4 floats between each arm, 32 in all, large enough for admitting keys to keep them fast, but allowing them to drive in when any thing gets under the wheel. The ends of the floats must be dovetailed a little into the shrouds; when one side is framed, frame the other to fellow it. This done, the wheel is ready to hang, but remember to face the shrouds between the arms with inch boards, nailed on with strong nails, to keep the wheel firm together.

ART. 11.

DIRECTIONS FOR DRESSING SHAFTS, &c.

The shaft for a water-wheel with 8 arms should be 16 square, or 16 sided, about 2 feet diameter, the tree to make it being 2 feet 3 inches at the top end. When cut down saw it off square at each end and roll it on level skids, and if it be not straight, lay the rounding side down and view it, to find the spot for the centre at each end. Set the big compasses to half its diameter, and sweep a circle at each end, plumb a line across each centre, and at each side at the circle, striking chalk lines over the plumb lines at each side from end to end, and dress the sides plumb to these lines; turn it down on one side, setting it level; plumb, line, and dress off the sides to a 4 square; set it exactly on one corner, and plumb, line, and dress off the corner to 8 square. In the same manner dress it to 16 square.

To cut it square off to its exact length, stick a peg in the centre of each end, take a long square (that may be made of boards) lay it along the corner, the short end against the end of the peg, mark on the square where the shaft is to be cut, and mark the shaft by it at every corner line, from mark to mark; then cut it off to the lines, and it will be truly square.

ART. 12.

TO LAY OUT THE MORTISES FOF THE ARMS.

Find the centre of the shaft at each end, and strike a circle, plumb a line through the centre at each end to be in the middle of two of the sides; make another scribe square across it, divide the distance equally between them, so as to divide the circle into 8 equal parts, and strike a line from each of them, from end to end, in the middle of the sides; measure from the top end about 3 feet, and mark for the arm of the water-wheel, and the width of the wheel, and make another mark. Take

a straight edge 10 feet pole, and put the end even with the end of the shaft, and mark on it even with the marks on the shaft, and by these marks measure for the arm at every corner, marking and lining all the way round. Then take the uppermost arms of each rim, and by them lay out the mortises, about half an inch longer than they are wide, which is to leave key room; set the compasses a little more than half the thickness of the arms, and set one foot in the centre line at the end of the mortise, striking a scribe each way for to lay out the width by; this done, lay out 2 more on the opposite side, to complete the mortises through the shaft. Lay out 2 more square across the first, one quarter the width of the arm, longer inward, towards the middle of the wheel. Take notice which way the locks of the arms wind, whether to right or left, and lay out the third mortises to suit, else it will be a chance whether they suit or not: these must be half the width of the arms, longer inwards.

The 4th set of mortises must be $\frac{3}{4}$ longer inwards than the width of the arms; the mortises should be made rather hollowing than rounding, that the arms may slip in easily and stand fair.

If there be three (which are called 6) arms to the cog-wheel, but 1 of them can be put through the sides of the shaft fairly; therefore, to lay out the mortises, divide the end of the shaft anew, into but 6 equal parts, by striking a circle on each end; and without altering the compasses, step from one of the old lines, six steps round the circle, and from these points strike chalk lines, and they will be the middle of the mortises, which may be laid out as before, minding which way the arms lock, and making 2 of the mortises 1-3 longer than the width of the arm, extending 1 on one side, and the other on the other side of the middle arm.

If there be but 2 (called 4) arms in the cog-wheel, (which will do where the number of cogs do not exceed 60) they will pass fairly through the sides, whether the shaft be 12 or 16 sided. One of these must be made one half longer than the width of the arms, to give room to put the arm in.

ART. 13.

TO PUT IN THE GUDGEONS.

Strike a circle on the ends of the shaft to let on the end bands; make a circle all round 2 1-2 feet from each end, and saw a notch all round half an inch deep. Lay out a square round the centres the size of the gudgeons, near the neck; lay the gudgeons straight on the shaft, and scribe round them for their mortises; let them down within 1-8 of an inch of being in the centre. Dress off the ends to suit the bands; make 3 keys of good seasoned white oak, to fill each mortise above the gudgeons, to key them in, those next to the gudgeons to be 3 1-4 inches deep at their inner end, and 1 1-2 inch at their outer end, the wedge or driviug key 3 inches at the head, and 6 inches longer than the mortise, that it may be cut off if it batters in driving; the piece next the band so wide as to rise half an inch above the shaft, when all are laid in. Then take out all the keys and put on the bands, and make 8 or 12 iron wedges about 4 inches long by 2 wide, 1-3 inch thick at the end, not much tapered except half an inch at the small end, on one side next the wood; drive them in on each side the gudgeon exceeding hard at a proper distance with a set. Then put in the keys again, and lay a piece of iron under each band between it and the key 6 inches long, half an inch thick in the middle, and tapering off at the ends; then grease the keys well with tallow and drive it well with a heavy sledge: after this drive an iron wedge half an inch from the two sides of each gudgeon 5 inches long, near half an inch thick, and as wide as the gudgeon.

ART. 14.

OF COG-WHEELS.

The great face cog-wheels require 3 (called 6) arms, if the number of cogs exceed 54, if less 4 will do. We

find by the table, example 43, that the cog-wheel must have 69 cogs, with 4 1-2 inches pitch, the diameter of its pitch circle 8 feet 2 1-3 inches, and of its outsides 8 feet 10 1-3 inches. It requires 3 arms 9 feet long, 14 by 3 3-4 inches; 12 cants 6 1-2 feet long, 16 by 4 inches. See it represented plate XVII, fig. 1.

To frame it, dress and lock the arms together, as fig. 6) as directed art. 10, only mind to leave 1-3 of each arm uncut, and to lock them the right way to suit the winding of the mortises in the shaft, which is best found by putting a strip of board in the middle mortise, and supposing it to be the arm, mark which way it should be cut, then apply the board to the arm, and mark it. The arms being laid on a truckle as directed art. 10, make a sweep the sides directing to the centre, 2 feet from the out end to scribe by; measure on the sweep half the diameter of the wheel, and by it circle out the back edges of the cants, all of one width in the middle; dress them, keeping the best faces for the face side of the wheel; make a circle on the arms 1-2 an inch larger than the diameter of the wheel, laying 3 of the cants with their ends on the arms at this circle at equal distance apart. Lay the other three on the top of them, so as to lap equally, scribe them both under and top, and gauge all for the laps from the face side; dress them out and lay them together, and joint them close; draw-pin them by an inch pin near their inside corners: this makes one half of the wheel shown fig. 5. Raise the centre level with that half, strike a circle near the outside and find the centre of one of the cants; then, with the sweep that described the circle, step on the circle 6 steps, beginning at the middle of the cant, and these steps will show the middle of all the cants or places for the arms. Make a scribe from the centre across each; strike another circle exactly at the corners, to place the corners of the next half by, and another about 2½ inches farther out than the inside of the widest part of the cant, to let the arms in by; lay on three of the upper cants, the widest part over the narrowest part of the lower half, the inside to be at the point where the corner circle crosses the centre lines. Saw off the ends at the centre scribes, and fit

them down to their places, doing the same with the rest. Lay them all on, and joint their ends together; draw pin them to the lower half by inch pins, 2 inches from their inmost edges, and 9 inches from their ends. Raise the centre level with the wheel; plane a little of the rough off the face, and strike the pitch circle and another 4 inches inside for the width of the face; strike another very near it, in which drive a chisel half an inch deep all round, and strike lines with chalk in the middle of the edge of the upper cants, and cut out of the solid half of the upper cants, which raises the face; divide the pitch circle into 69 equal parts, $4\frac{1}{2}$ inches pitch, beginning and ending in a joint; strike two other circles each 2 1-2 inches from the pitch circle, and strike central scribes between the cogs, and where they cross the circles put in pins, as many as there are cogs, half on each circle; find the lowest part on the face, and make the centre level with it; look across in another place square with the first, and make it level with the centre also; then make the face straight from these 4 places, and it will be true.

Strike the pitch circle, and divide it over again, and one of each side of it, 1 inch distance for the cog mortises; sweep the outside of the wheel and inside of the face, and two circles 3-4 of an inch from them, to dress off the corners; strike a circle of two inches diameter on the centre of each cog, and with the sweep strike central scribes at each side of these circles for the cog mortises; bore and mortise half through; turn the wheel, dress and mortise the back side, leaving the arms from under it; strike a circle on the face edge of the arms, equal in diameter to that struck on the face of the half wheel, to let them in by; saw in square and take out $4\frac{1}{2}$ inches, and let them into the back of the wheel 1 1-4 inch deep, and bore a hole 1 1-2 inch into each arm, to pin it to the wheel.

Strike a circle on the arms one inch less than the diameter of the shaft, make a key 8 inches long, $1\frac{1}{2}$ thick, $3\frac{1}{4}$ at the butt, and $2\frac{1}{2}$ inches at the top end, and by it lay out the mortises; two on each side of the shaft, in each arm to hang the wheel by.

ART. 15.

OF SILLS, SPUR-BLOCKS, AND HEAD-BLOCKS.

See a side view of them in plates XIII, XIV, XV, and XVI, and a top view of them with their keys at the end of the shaft, plate XVIII. The sills are generally 12 inches square. Lay them on the wall as firm as possible, and one 3 feet farther out, on these lay the spurs, which are 5 feet long, 7 by 7 inches, 3 feet apart, notched and pinned to the sills; on these are set the head-blocks, 14 by 12 inches, 5 feet long, let down with a dove-tail shoulder between the spurs, to support keys to move it endways, and let 2 inches into the spurs with room for keys, to move it sideways, and hold it to its place; see fig. 33 and 34, plate XVIII. The ends of the shaft are let 2 inches into the head-blocks, to throw the weight more on the centre.

Provide two stones 5 or 6 inches square, very hard and clear of grit, for the gudgeons to run on, let them into the head-blocks, put the cog-wheel into its place, and then put in the shaft on the head-blocks in its place.

Put in the cog-wheel arm, lock them together and pin the wheel to them; then hang the wheel first by the keys, to make it truly round, and then by side wedges, to make it true in face; turn the wheel, and make two circles one on each side of the cog-mortises, half an inch from them, so that the head of the cogs may stand between them equally.

ART. 16.

OF COGS; THE BEST TIME FOR CUTTING, AND WAY OF SEASONING THEM.

They should be cut 14 inches long, 3 1-4 inches square, when the sap runs at its fullest, which should be done at least a year before they are used, that they may dry without cracking. If either hickory or white-oak is cut when the bark is set, they will worm-eat, and if dried hastily, will crack; to prevent which, boil them

and dry them slowly, or soak them in water, a year, (20 years in mud and fresh water would not hurt them ;) when they are taken out they should be put in a hay-mow under the hay, which when foddered away they will dry without cracking ; but this often takes too long time. I have discovered the following method of drying them in a few days without cracking : I have a malt-kiln with a floor of laths two inches apart. I shank the cogs, hang them shank downwards, between the laths cover them with a hair-cloth, make a wood fire, and the smoke preserves them from cracking. Some dry them in an oven, which ruins them. Boards, planks, or scantling are best dried in a kiln, covered so as to keep the smoke amongst them. Instead of a malt kiln, dig a cave in the side of a hill, 6 feet deep, 5 or 6 feet wide, with a post in each corner with plates on them, on which lay laths on edge, and pile the cogs on end nearly perpendicular, so that the smoke can pass freely through or amongst them. Cover slightly with boards and earth, make a slow fire and close up the sides, and renew the fire once a day for 12 or 15 days, they will dry without cracking. Experienced by James Dellet, Mill-wright.

ART. 17.

OF SHANKING, PUTTING IN, AND DRESSING OFF COGS.

Straighten one of the heart sides for the shank, make a pattern, the head 4 and shank 10 inches long, and 2 inches wide at the head, $1\frac{3}{4}$ at the point; lay it on the cog, scribe the shank and shoulders for the head, saw in and dress off the sides ; make another pattern of the shank, without the head, to scribe the sides and dress off the backs by, laying it even with the face, which is to have no shoulder ; take great care in dressing them off, that the axe does not strike the shoulder, if it does it will crack there in drying (if they be green) ; fit and drive them in the mortises exceeding tight, with their shoulders foremost when at work. When the cogs are all in, fix two

pieces of scantling for rests, to scribe the cogs by, one across the cog-pit near the cogs, another in front of them, fix them firm. Hold a pointed tool on the rest, and scribe for the length of the cogs by turning the wheel, and saw them off $3\frac{1}{2}$ inches long; then move the rest close to them, and fix it firm; find the pitch circle on the end of the cogs, and by turning the wheel describe it there.

Describe another $\frac{1}{4}$ of an inch outside thereof, to set the compass in to describe the face of the cogs by, and another at each side of the cogs to dress them to their width: then pitch the cogs by dividing them equally, so that in stepping round, the compasses may end in the point where they began; describe a circle in some particular place with the pitch that it may not be lost; these points must be as near as possible, of a proper distance for the centre from the back of the cogs; find the cog that this point comes nearest to the back, and set the compasses from that point to the back of the cog, and with this distance set off the backs of all the cogs equally, on the circle 1-4 of an inch outside of the pitch circle, and from these points last made, set off the thickness of the cogs, which should be 2 1-8 inches in this case.

Then describe the face and back of the cogs by setting the compasses in the hindmost point of one cog, and sweeping over the foremost point of another for the face, and in the foremost point of one, sweeping over the hindmost of the other, for the back part; dress them off on all sides, tapering about 1-8 of an inch in an inch distance, try them by a gauge to make them all alike, take a little of the corners off, and they are finished.

ART. 18.

OF THE LITTLE COG-WHEEL AND SHAFT.

The process of making this is similar to that of the big cog-wheel. Its dimensions we find by the table, and the same example 43, to be 52 cogs, 4 1-4 pitch. Diameter of pitch circle 5 feet 10 1-3 inches, and from out to out 6 feet 6 inches.

It requires 2 arms 6 feet 6 inches long, 11 by $3\frac{1}{4}$ inches; 8 cants 5 feet 6 inches, 17 by $3\frac{1}{2}$ inches. See it, plate XVII, fig. 4.

Of the Shaft.

Dress it 8 feet long, 14 by 14 square, and describe a circle on each end 14 inches diameter; strike two lines through the centre parallel to the sides, and divide the quarters into 4 equal parts each; strike lines across the centre at each part at the end of these lines; strike chalk lines from end to end to hew off the corners by, and it will be 8 square; lay out the mortises for the arms, put on the bands, and put in the gudgeons, as with the big shaft.

ART. 19.

DIRECTIONS FOR MAKING WALLOWERS AND TRUNDLES.

By example 43 in the table, the wallower is to have 26 rounds $4\frac{1}{2}$ pitch. Diameter of its pitch circle is 3 feet $1\frac{1}{4}$ inch, and 3 feet $4\frac{1}{4}$ inches from outsides: see fig. 3. plate XVII. Its head should be $3\frac{1}{2}$ inches thick, doweled truly together, or made double with plank crossing each other. Make the bands three inches wide, 1-6 of an inch evenly drawn; the heads must be made to suit the bands, by setting the compasses so that they will step round the inside of the band in 6 steps; with this distance sweep the head, allowing about 1-16 of an inch outside in dressing to make such a large band tight. Make them hot alike all round with a chip fire, which swells the iron; put them on the head while hot, and cool them with water to keep them from burning the wood too much, but not too fast lest they snap: the same for hooping all kinds of heads.

Dress the head fair after banded, and strike the pitch circle and divide it by the same pitch of the cogs; bore the holes for the rounds with an auger at least $1\frac{1}{2}$ inch; make the rounds of the best wood 2 3-8 inches diame-

ter, and 11 inches between the shoulders, the tenons 4 inches, to fit the holes loosely until within 1 inch of the shoulder, then drive tight. Make the mortises for the shaft in the heads, with notches for the keys to hang it by. When the rounds are all drove in to the shoulders, observe whether they stand straight, if not, they may be set fair by putting the wedges nearest to one side of the tenon, so that the strongest part may incline to draw them straight: this should be done with both heads.

ART. 20.

OF FIXING THE HEAD-BLOCKS AND HANGING THE WHEELS.

The head-blocks for the wallower shaft, are shown in plate XVIII. Number 19 is one called a spur, 6 feet long and 15 inches deep, one end of which at 19 is let one inch into the top of the husk-sill, which sill is $1\frac{1}{2}$ inch above the floor, the other end tenoned strongly into a strong post 14 by 14 inches, 12 or 14 feet long, standing near the cog-wheel on a sill in the bottom of the cog-pit; the top is tenoned into the husk-plank; these are called the tomkin posts. The other head-blocks appear at 20 and 28. In these large head-blocks there are small ones let in, that are 2 feet long and 6 inches square, with a stone in each for the gudgeons to run on. That one in the spur 19 is made to slide, to put the wallower out and in gear by a lever screwed to its side.

Lay the centre of the little shaft level with the big one, so as to put the wallower to gear 2-3 the thickness of the rounds deep into the cog-wheel; put the shaft into its place and hang the wallower, and gauge the rounds to equal distance where the cogs take. Hang the cog-wheel, put in the cogs, make the trundle as directed for the wallower. See plate XVII, fig. 4.

ART. 21.

DIRECTIONS FOR PUTTING IN THE BALANCE-RYNE.

Lay it in the eye of the stone, and fix it truly in the centre; to do which make a sweep by putting a long pin

through the end to reach into and fit the pivot hole in the balance ryne; by repeated trials on the opposite sides fix it in the centre; then make a particular mark on the sweep and others to suit it on the stone, scribe round the horns, and with picks and chisels sink the mortises to their proper depth, trying by the sweep if it be in the centre, by the particular marks made for the purpose. Put in the spindle with the foot upwards and the driver on its place, while one holds it plumb. Set the driver over two of the horns, if it has four, but between them if it has but two. When the neck is exactly in the centre of the stone, scribe round the horns of the driver, and let it into the stone, nearly to the balance, if it has four horns. Put the top of the spindle in the pivot-hole to try whether the mortses let it down freely on both sides.

Make a tram to set the spindle square by, as follows: take a piece of board, cut a notch in one side, at one end, and hang it on the top of the spindle, by a little peg in the shoulder of the notch, to go in the hole in the foot to keep it on, let the other end reach down to the edge of the stone, take another piece, circle out one end to fit the spindle neck, and make the other end fast to the lower end of the hanging piece near the stone, so as to play round level with the face of the stone, resting on the centre-hole in the foot, and against the neck, put a bit of quill through the end of the level piece, that will touch the edge of the stone as it plays round. Make little wedges and drive them in behind the horns of the driver, to keep both ends at once close to the sides of the mortises they bear against when at work, keeping the pivot or cock-head in its hole in the balance, try the tram gently round, and mark where the quill touches the stone first, and dress off the bearing sides of the mortises for the driver until it will touch equally round, giving the driver liberty to move endways and sideways to let the stone rock an inch any way. The ryne and driver must be sunk 3-4 of an inch below the face of the stone. Then hang the trundle firmly and truly on the spindle, put it in its place to gear in the little cog-wheel.

ART. 22.

TO BRIDGE THE SPINDLE.

Make a little tram of a piece of lath, 3 inches wide at one end, and 1 inch at the other, make a mortise in the wide end, and put it on the cock-head, and a piece of quill in the small end, to play round the face of the stone: then, while one turns the trundle, another observes where the quill touches first, and alters the keys of the bridge-tree, driving the spindle-foot toward the part the quill touches, until it touches equally all round. Case the stone neatly round within 2 inches of the face.

ART. 23.

OF THE CRANE AND LIGHTER-STAFF.

Make a crane for taking up and putting down the stone, with a screw and bale. See it represented in Evans's part, pl. XI. fig. 2 and 3. Set the post out of the way as much as possible, let it be 9 by 6 inches in the middle, the arm 9 by 6, brace 6 by 4, make a hole plumb over the spindle, for the screw, put an iron washer on the arm under the female screw, nail it fast, the screw should be above half the diameter of the stone, in the worm, and 10 inches below it, the bale to touch only at the ends to give the stone liberty to turn, the pins to be 7 inches long, 1 1-8 thick, the bale to be 2½ inches wide in the middle, and 1¾ inch wide at the end; all of the best iron, for if either of them break the danger would be great. The holes in the stone should be nearest the upper side of it. Raise the runner by the crane, screw and bale, turn it and lay it down, with the horns of the driving ryne in their right places, as marked, it being down, as appears in pl. XXI. fig. 9. Make the lighter-staff C C to raise and lower the stone in grinding, about 6 feet long, 3½ by 2½ inches at the large end, and 2 inches square at the small end, with a knob on the upper side. Make a mortise through the butt end for the bray-iron to pass

through, which goes into a mortise 4 inches deep in the end of the bray at b, and fastened with a pin; it may be 2 inches wide, half an inch thick, a plain bar with one hole at the lower end, and 5 or 6 at the upper end, set in a staggering position. This lighter is fixed in front of the meal-beam, at a proper height to be handy to raise or lower at pleasure; a weight of 4 lb. is hung to the end of it by a strap, that laps two or three times round, and the other end fastened to the post below, that keeps it in its place. Play the lighter up and down, and observe whether the stone rises and falls flat on the bed-stone, if it does, draw a little water, and let the stone move gently round, then see that all things be right, and draw a little more water, let the stone run at a middling rate, and grind the faces a few minutes.

ART. 24.

DIRECTIONS FOR MAKING A HOOP FOR THE MILL-STONE.

Take a white pine or poplar board, 8 inches longer than will go round the stone, and 2 inches wider than the top of the stone is high, dress it smooth, and gauge it one inch thick, run a gauge mark 1-6 of an inch from the outside, divide the length into 52 parts, and saw as many saw-gates square across the inside to the gauge-line. Take a board of equal width, 1 foot long, nail one half of it on the outside at one end of the hoop, lay it in water a day or two to soak, or sprinkle the outside well an hour or two with hot water. Bend it round so that the ends meet, and nail the other end to the short board, put sticks across inside in every direction to press out the parts that bend least, and make it truly round. Make a cover for the hoop, such as is represented in plate XIX, fig. 23, 8 square inside, and 1 inch outside the hoop. It consists of 8 pieces lapped over one another, the black lines showing the joints as they appear when made, the dotted lines the under parts of the laps. Describe it on the floor, and make a pattern to make all

the rest by; dress all the laps, fit and nail them together by the circle on the floor, and then nail it on the hoop; put the hoop over the stone and scribe it to fit the floor in its place.

ART. 25.

OF GRINDING SAND TO FACE THE STONES.

Lay boards over the hoop to keep the dust from flying, and take a bushel or two of dry, clean, sharp sand, teem it gently in the eye, while the stones move at a moderate rate, continuing to grind for an hour or two; then take up the stones, sweep them clean, and pick the smoothest hardest places, and lay the stone down again, and grind more sand as before, turning off the back, (if it be a burr) taking great care that the chisel does not catch; take up the stone again, and make a red staff, in length the diameter of the stone, 3 by $2\frac{1}{2}$ inches, paint it with red paint and water, and rub it over the face of the stones in all directions, the red will be left on the highest and hardest parts, which must be pecked down, making the bed-stone perfectly plain, and the runner a little concave about 1-6 of an inch at the eye, and lessening gradually to about 8 inches from the skirt. If they be close and have much face they need not touch or flour so far, as if they are open and have but little face; those things are left to the judgment of the mill-wright and miller.

ART. 26.

DIRECTIONS FOR LAYING OUT THE FURROWS IN THE STONES, &c.

If they be five feet in diameter, divide the skirt into 16 equal parts, called quarters, if 6 feet, into 18, if 7 feet, into 20 quarters. Make two strips of board, one an inch, and the other 2 inches wide; stand with your face to the eye, and if the stone turns to the right when at work, lay the strip at one of the quarter divisions, and the other at the left hand side close to the eye, and mark

with a flat pointed spike for a master furrow; they all are laid out the same way in both stones, for when their faces are together, the furrows should cross each other like shears in the best position for cutting cloth. Then, having not less than 6 good picks, proceed to pick out all the master furrows, making the edge next the skirt and the end next the eye the deepest, the feather edge not half so deep as the back.

When all the master furrows are picked out, lay the broad strip next to the feather edges of all the furrows, and mark the head lands of the short furrows, then lay the same strip next the back edges, and mark for the lands, and lay the narrow strip, and mark for the furrows, and so on mark out all the lands and furrows, minding not to cross the head lands, but leaving it between the master furrows and the short ones of each quarter. But if they be close country stones, lay out both furrows and land with the narrow strip.

The neck of the spindle must not be wedged too tight else it will burn loose; bridge the spindle again; put a collar round the spindle neck, but under it put a piece of an old stocking, with tallow rolled up in it, about a finger thick; tack it close round the neck; put a piece of stiff leather about 6 inches diameter on the cock-head under the driver, to turn with the spindle and drive off the grain, &c. from the neck; grease the neck with tallow every time the stone is up.

Lay the stone down and turn off the back smooth, and grind more sand. Stop the mill; raise the stone a little, and balance it truly with weight laid on the lightest side. Take lead equal to this weight, melt it, and run it into a hole made in the same place in the plaister, largest at bottom to keep it in, fill the hole with plaister, take up the runner again, try the staff over them, and if in good face give them a nice dressing, and lay them down to grind wheat.

ART. 27.

DIRECTIONS FOR MAKING A HOPPER, SHOE, AND FEEDER.

The dimension of the hopper of a common mill is 4 feet at the top, and 2 feet deep, the hole in the bottom 3 inches square, with a sliding gate in the bottom of the front to lessen it at pleasure: the shoe 10 inches long, and 5 wide in the bottom, of good sound oak. The side 7 or 8 inches deep at the hinder end, 3 inches at the foremost end, 6 inches longer than the bottom at the fore end, slanting more than the hopper behind, so that it may have liberty to hang down 3 or 4 inches at the fore end, which is hung by a strap called the feeding-string, passing over the fore end of the hopper-frame, and lapping round a pin in front of the meal-beam, that will turn by the hand, called the feeding-screw.

The feeder is a piece of wood turned in a lathe, about 20 inches long, 3 inches diameter in the middle against the shoe, tapered off to 1½ inches at the top; the lower end is banded and a forked iron drove in it, that spans over the ryne fitting into notches made on each side, to receive it, right above the spindle, and turns with it; the upper end running in a hole in a piece across the hopper-frame. In the large part next the shoe are set 6 iron knockers, 7 inches long, half an inch diameter, with a tang at each end, turned square to drive into the wood, these knock against, and shake the shoe, and thereby shake in the grain regularly.

Then put grain into the hopper, draw water on the mill, regulate the feed by turning the feed-screw, until the stream falling into the eye of the stone, is proportioned to the size thereof, or the power of the mill. Here ends the mill-wright's work, with respect to grinding, and the miller takes charge thereof.

ART. 28.

OF BOLTING CHESTS AND REELS.

Bolting-chests and reels are of different lengths, according to the use they are for. Common country chests (a

top view of one of which is shown, pl. VII. fig. 9,) are commonly about 10 feet long, 3 feet wide, and 7 feet 4 inches high, with a post in each corner, the bottom 2 feet from the floor, with a board 18 inches wide, set slanting in the back side, to cast the meal forward in the chest, to make it easily taken up; the door of the whole length of the chest, and two feet wide, the bottom side board below the door 16 inches wide.

The shaft of the reel equal in length with the chest, 4 inches diameter, 6 square, two bands on each end, 3 1-4 and 3 3-4 diameter, gudgeons 13 inches long, 7-8 of an inch diameter; 8 inches in the shaft, round 2 1-2 inches at the neck, with a tenon for a socket or handle, six ribs 1 1-2 inch deep, 1 1-8 inch thick, half an inch shorter at the tail, and 1 1-2 inch at the head, than the shaft, to leave room for the meal to be spouted in at the head, and the bran to fall at the tail; four sets of arms, that is, 12 of them, 1 1-2 inch wide, and 5-8 thick. The diameter of the reel from out to out of the ribs, is one-third part of the double width of the cloth. A round wheel of inch boards, and diameter equal to the outside of the ribs, $4\frac{1}{2}$ inches wide, measuring from the outside towards the centre, (which is taken out) is to be framed, to the head of the reel, to keep the meal from falling out at the head unbolted. Put a hoop $4\frac{1}{4}$ inches wide, and $\frac{1}{4}$ thick, round the tail, to fasten the cloth to. The cloth is sewed two widths of it together, to reach round the reel; putting a strip of strong linen 7 inches wide, at the head, and 5 inches at the tail of the cloth, to fasten it to the reel by. Paste a strip of linen, soft paper, or shammy leather (which is the best) $1\frac{1}{2}$ inch wide on each rib, to keep the cloth from fretting. Then put the cloth on the reel tight, and sew or nail it to the tail, and stretch it lengthways as hard as it will bear, nailing it to the head.

N. B. 6 yards of cloth covers a 10 feet reel.

Bolting-reels for merchant, are generally longer than for country, work, every part should be stronger in proportion as necessary. They are best when made to suit the wide cloths. The socket gudgeons at the head should

be much stronger, they being apt to wear out, and troublesome to repair.

The bolting hopper is made through the floor above the chest, 12 inches square at the upper and 10 inches at the lower end; the foremost side 5 inches and the back side 7 inches from the top of the chest.

The shoe 2 feet long at the bottom of the side pieces, slanting to suit the hopper at the hinder end, set 4 inches higher at the hinder than the fore end, the bottom 17 inches long and 10 inches wide. There should be a bow of iron riveted to the fore end to rest on the top of the knocking wheel, fixed on the socket gudgeon at the head of the chest, which is 10 inches diameter, 2 inches thick, with 6 half rounds cut out of its circumference by way of knockers, to strike against the bow, and lift the shoe $\frac{3}{4}$ of an inch every stroke to shake in the meal.

ART. 29.

OF SETTING BOLTS TO GO BY WATER.

The bolting reels are set to go by water as follows:

Make a bridge 6 by 4 inches, and 4 inches longer than the distance of the tomkin posts, described art. 20; set it between them on rests fastened into them, 10 inches below the cogs of the cog-wheel, and the centre of it half the diameter of the spur-wheel in front of them; on this bridge is set the step gudgeon, of an upright shaft, with a spur-wheel of 16 or 18 cogs to gear into the cog-wheel. Fix a head-block to the joists of the 3d floor for the upper end of this shaft, put the wheel 28, plate VII, on it; hang another head-block to the joists of the 2d floor near the corner of the mill at 6, for the step of the short upright shaft that is to be fixed there, to turn the reels 1 and 9. Hang another head-block to the joists of the 3d floor for the upper end of the said short upright, and fix also head-blocks for the short shaft at the head of the reels, so that the centres of all these shafts will meet. Then fix a hanging post in the corner 5, for

the gudgeon of the long horizontal shaft 27—5 to run in. After the head-blocks are all fixed, then measure the length of each shaft, and make them as follows, viz.

The upright shaft $5\frac{1}{2}$ inches for common mills, but if for merchant-work, with Evans's elevators, &c. added, make it larger 6 or 7 inches; the horizontal shaft 27—5 and all the other 5 inhes diameter. Put a socket-gudgeon in the middle of the long shafts to keep them steady; make them 8 or 16 square, except at the end where the wheels are hung, where they must be 4 square. Band their ends, put in the gudgeons, put them in their proper places in the head-blocks, to mark where the wheels are to be put on them.

ART. 30.

OF MAKING BOLTING WHEELS.

Make the spur-wheel for the first upright with a $4\frac{1}{2}$ inch plank, the pitch of the cogs the same as the cog-wheel, into which it is to work, put two bands 3-4 of an inch wide, one on each side of the cogs, and a rivet between each cog to keep the wheel from splitting.

To proportion the cogs in the wheels to give the bolts the right motion, the common way is—

Hang the spur-wheel and set the stones to grind with a proper motion, and count the revolutions of the upright shaft in a minute, and compare its revolutions with the revolutions that a bolt should have, which is about 36 revolutions in a minute. If the upright goes 1-6 more, put 1-6 less in the first driving-wheel than in the leader, suppose 15 in the driver then 18 in the leader: but if their difference be more (say one half) there must be a difference in the next two wheels; observing, that if the motion of the upright shaft be greater than the bolt should be, then the driving-wheel must be proportionably less than the leader; but if it be slower, then the driver must be greater in proportion. The common size of bolting wheels is from 14 to 20 cogs; if less than 14 the head-blocks will be too near the shafts.

Common bolting wheels should be made of plank at least 3 inches thick, well seasoned, and are best to be as wide as the diameter of the wheel, and banded with bands near as wide as the thickness of the wheel, made generally of rolled iron, about 1-8 of an inch thick. Some make them of two inch plank, crossed, and no bands: but this proves no saving, as they are apt to go to pieces in a few years. For hooping wheels see art. 19, and for finding the diameter of the pitch circle see art. 9. The wheels are generally two inches more in diameter than the pitch circle if banded; but if not, they should be more. The pitch or distance of the cogs are different, if to turn 1 or 2 bolts $2\frac{1}{2}$ inches, but if more $2\frac{3}{4}$: but if much heavy work, they should not be less than 3 inches. Their cogs are half the pitch in thickness, the shank to drive tight in an inch auger hole.

When the mortises are made for the shafts in the head, and notches for the keys to hang them, drive the cogs in and pin their shanks at the back side, and cut them off half an inch from the wheel.

Hang the wheels on the shafts so that they will gear a proper depth, about 2-3 the thickness of the cogs; dress all the cogs to equal distance by a gauge; then put the shafts in their places, the wheels gearing properly, and the head-blocks all secure, set them in motion by water. Bolting reals should turn to drop the meal on the back side of the chest, as it will then hold more, and will not cast out the meal when the door is opened.

ART. 31.

OF ROLLING-SCREENS.

These are circular sieves moved by water, and are particularly useful in cleaning wheat for merchant work. They are of different constructions.

1st. Those of one coat of wire with a screw in them.

2d. Those of two coats, the inner one nailed to 6 ribs, the outer one having a screw between it and the inner one.

3. Those of a single coat and no screw.

The first kind answers well in some, but not in all cases, because they must turn a certain number of times before the wheat can get out, and the grain has not so good an opportunity of separating, there being nothing to change its position, it floats a considerable way with the same grains uppermost.

The double kind are better because they may be shorter and take up less room; and worse, for being more difficult to be kept clean.

The 3d kind has this advantage; we can keep the grain in it a longer or shorter time at pleasure, by raising or lowering the tail end, and is also tossed about more; but they must be longer. They are generally 9 or 10 feet long, 2 feet 4 inches diameter, if to clean for two or three pair of stones, but if for more, they should be larger accordingly: will clean for from one to six pair of stones. They are made 6 square, with 6 ribs, which lie flatwise, the outer corners taken off to leave the edge $\frac{1}{4}$ of an inch thick; the inner corners so as to bring it nearly to sharp edges, the wire work nailed on with 14 ounce tacks.

They are generally moved by the same upright shaft that moves the bolts, by a wheel on its upper end with two sets of cogs: those that strike downwards gearing into a wheel striking upwards that turns a laying shaft, with two pulleys on the other end, one of 24 inches diameter, to turn a fan with quick motion, the other 8 inches, over which passes a strap to a pulley 24 inches diameter, on the gudgeon of the rolling screen, to reduce its motion to about 15 revolutions in a minute. See pl. XIX. fig. 23. This may do for mills in the small way, but where they are in perfection for merchant-work, with elevators, &c. and have to clean wheat for 2, 3, or 4 pair of stones, they should be moved by cogs.

ART. 32.

OF FANS.

The Dutch fan is a machine of great use for blowing the dust and other light stuff from among the wheat;

there are various sorts of them; those that are only for blowing the wheat, as it falls from the rolling-screen, are generally about 15 inches long, and 14 inches wide in the wings, and have no riddle or screen in them.

To give it motion, put a pulley 7 inches diameter on its axle for a band to run on, from the pulley on the shaft that moves the screen of 24 inches diameter, to give it a swift motion; when the band is slack it slips a little on the small pulley, and the motion is slow; but when tight the motion is quicker; by this the blast is regulated.

Some use Dutch fans complete, with riddle and screen under the rolling screen for merchant-work, and again use the fan alone for country-work.

The wings of those, which are the common farmers wind-mills or fans, are 18 inches long, and 20 inches wide, but in mills they are set in motion with a pulley instead of a cog-wheel and wallower.

ART. 33.

OF THE SHAKING SIEVE.

They are of considerable use in country mills, to sift indian meal, separating it into several degrees of fineness if required, and take the hulls out of buckwheat meal, that are apt to cut the bolting-cloth, and the dust out of the grain, if rubbed before ground; and are sometimes used to clean wheat or screenings instead of rolling screens.

If they are for sifting meal they are 3 feet 6 inches long, 9 inches wide, $3\frac{1}{2}$ inches deep; see it plate VI. fig. 16. The wire-work is 3 feet long, 8 inches wide: across the bottom of the tail end is a board 6 inches wide, to the top of which the wire is tacked, and then this board and wire tacked to the bottom of the frame, leaving an opening at the tail end for the bran to fall into the box 17, the meal falling into the meal-trough 15, the head-piece should be strong to hold the iron bow at 15, through which passes the lever that shakes the sieve, in the following manner: Take two pieces of hard wood 15 inches long, and as wide

as the spindle, and so thick that when one is put on each side just above the trundle, it will make it 1½ inch thicker than the spindle is wide. The corners of these are taken off to a half round, and they are tied to the spindle with a small strong cord. These are for to strike against the lever that works on a pin near its centre, which is fastened to the sieve, and shakes it as the trundle goes round; see it represented plate XVIII. This lever must always be put to the contrary side of the spindle, that it is of the meal-spout, else it will draw the meal to the upper end of the sieve: there must be a spring fixed to the sieve to draw it forward as often as it is driven back. It must hang on straps and be fixed so as to be easily set to any descent required, by means of a roller in form of the feeding screw, only longer, round which the strap winds.

Having now given directions for making and putting to work, all the machinery of one of the completest of the old fashioned grist-mills, that may do merchant-work in the small way as represented by plates XVIII, XIX, XX, XXI; but not to near so much advantage as with the late and new improvements, which are shown by plate X.

ART. 34.

OF THE USE OF DRAUGHTING TO BUILD MILLS BY, &c.

Perhaps some are of opinion that draughts are useless pictures of things, serving only to please the fancy. This is not what I intend by them; but to give the reader true ideas of the machines, &c. described, or to be made. They are all drawn on a small scale of 1-8 of an inch for a foot, in order to suit the size of the book, except plate XVII, which is quarter of an inch for a foot, and this scale I recommend, as most buildings will come on the size of a common sheet of paper.

N. B. Plate XXIV, was made after the above directions, and has its explanations to suit it.

The great use of draughting mills, &c. to build by, is by conveying our ideas more plain, than is possible to be done by writing or words, which may be miscon-

strued or forgotten; but a draught well drawn, speaks for itself, when once understood by the artist; who, by applying his dividers to the draught and to the scale, finds the length, breadth and height of the building, or the dimensions of any piece of timber, and its place in the building, &c.

By the draught, the bills of scantling, boards, rafters, laths, shingles, &c. &c. are known and made out; it should show every wheel, shaft, and machine, and their places. By it we can find whether the house is sufficient to contain all the works that are necessary to carry on the business; the builder or owner understands what he is about, and carries on cheerfully without error; it directs the mason where to put the windows, doors, navel-holes, the inner walls, &c. whereas, if there be no draught, every thing goes on, as it were, in the dark; much time is lost and errors are committed to the loss of many pounds. I have heard a man say, he believed his mill was 500*l.* better, by having employed an experienced artist, to draw him a draught to build it by. And I know by experience the great utility of them. Every master builder ought, at least, to understand them.

ART. 35.

DIRECTIONS FOR PLANNING AND DRAUGHTING MILLS.

1st. If it be a new seat, view the ground where the dam is to be, and where the mill-house is to stand, and determine on the height of the top of the water in the head-race where it is taken out of the stream; and level from it for the lower side of the race down to the seat of the mill-house, and mark the level of the water in the dam there.

2d. Begin where the tail-race is to empty into the stream, and level from the top of the water up to the mill-seat, noticing the depth thereof in places as you pass along, which will be of use in digging it out.

Then find the total fall, allowing 1 inch to a rod for fall in the races, but if they are very wide and long, less will do.

Then, supposing the fall to be 21 feet 9 inches, which is sufficient for an overshot mill, and the stream too light for an undershot, consider well what size stone will suit, for I do not recommend a large stone to a weak, nor a small one to a strong stream. I have proposed stones 4 feet diameter for light, and 4,6 for middling, and 5 or 5 feet 6 inches diameter for heavy streams. Suppose you determine on stones 4 feet, then look in table I, (which is for stones of that size) column 2, for the fall that is nearest 21 feet 9 inches, your fall, and you find it in the 7th example. Column 3 contains the head of water over the wheel 3 feet; 4th, the diameter of the wheel 18 feet; 5th, its width, 2 feet 2 inches, &c. for all the proportions to make the stone revolve 106 times in a minute.

Having determined on the size of the wheels and size of the house, heights of the stories to suit the wheels, and machinery it is to contain, and business to be carried on therein, proceed to draw a ground plan of the house, such as plate XVIII, which is 32 by 55 feet. See the description of the plate. And for the second story, as plate XIX, &c. for the 3d, 4th and 5th floors, if required, taking care to plan every thing for the best, and so as not to clash one with another.

Draw an end view, as plate XX, and a side view as plate XXI. Take the draught to the ground and stake out the seat of the house. It is commonly best to set that corner of an overshot mill that the water comes in at farthest in the bank; but take great care to reconsider and examine every thing more than once whether it be planned for the best; because, much labour is often lost for want of due consideration, and by setting buildings in, and laying foundations on wrong places. This done, you may from the draughts make out the bills of scantling and iron work.

ART. 36.

BILLS OF SCANTLING FOR A MILL, 32 BY 55 FEET, 3 STORIES HIGH, SUCH AS DESCRIBED PLATES XVIII, XIX, XX, AND XXI. THE WALLS OF MASON WORK.

For the first Floor.

2 sills, 29 feet long, 8 by 12 inches, to lay on the walls for the joists to lay on.

48 joists, 10 feet long, 4 by 9 inches; all of timber that will last well in damp places.

For the second Floor.

2 posts, 9 feet long, 12 by 12 inches.

2 girders, 30 feet long, 14 by 16 do.

48 joists, 10 feet long, 4 by 9 do.

For the Floor over the Water-house.

1 cross girder, 30 feet long, 12 by 14 inches, for one end of the joists to lay on.

2 posts to support the girder, 12 feet long, 12 by 12 inches.

16 joists, 13 feet long, 4 by 9 inches; all of good white-oak or other timber that will last in damp places.

For the third Floor.

4 posts, 9 feet long, 12 by 12 inches, to support the girders.

2 girder-posts, 7 feet long, 12 by 12 inches, to stand on the water-house.

2 girders, 53 feet long, 14 by 16 inches.

90 joists, 10 feet long, 4 by 9 inches,

For the fourth Floor.

6 posts, 8 feet long, 10 by 10 inches, to support the girders.

2 girders, 53 feet long, 13 by 15 inches.

30 joists, 10 feet long, 4 by 8 do. for the middle tier of the floor.

60 do, 12 feet do. 4 by 8, for the outside tiers, which extends 12 inches over the walls, for the rafters to stand on.

2 plates, 54 feet long, 3 by 10 inches: these lay on the top of the walls, and the joists on them.

2 raising pieces, 55 feet long, 3 by 5 inches; these lay on the ends of the joists for the rafters to stand on.

For the Roof.

54 rafters, 22 feet long, 3 inches thick, 6½ wide at bottom, and 4½ at top end.
25 collar beams, 17 feet long, 3 by 7 inches.
2760 feet of laths, running measure.
7000 shingles.

For Doors and Window-Cases.

12 pieces, 12 feet long, 6 by 6 inches, for door cases.
36 do. 8 feet long, 5 by 5 inches for window-cases.

For the Water-House.

2 sills, 27 feet long, 12 by 12 inches.
1 do. 14 feet long, 12 by 12 do.
2 spur-blocks, 4 feet 6 inches long 7 by 7 do.
2 head-blocks, 5 feet long, 12 by 14 do.
4 posts, 10 feet long, 8 by 8 to bear up the penstock.
2 capsails, 9 feet long, 8 by 10, for the penstock to stand on.
4 corners posts, 5 feet long, 4 by 6 inches, for the corners of the penstock.

For the Husk of a Mill of one Water-wheel and two Pair of Stones.

2 sills, 24 feet long, 12 by 12 inches,
4 corner posts, 7 feet long, 12 by 14 inches.
2 front posts, 8 feet long, 8 by 12 do.
2 back posts, 8 feet do. 10 by 12 inches, to support the back ends of the bridge-trees.
2 other back posts 8 feet long, 8 by 8 inches.
2 tomkin posts, 12 feet long, 12 by 14 do.
2 interties, 9 feet long, 12 by 12 inches, for the outer ends of the little cog-wheel shafts to rest on.
2 top pieces, 10 feet 6 inches long, 10 by 10 inches.
2 beams, 24 feet long, 16 by 16 inches.
2 bray-trees, 8½ feet long, 6 by 12 inches.
2 bridge-trees, 9 feet long, 10 by 10 inches.
4 plank, 8 feet long, 6 by 14 inches, for the stone-bearers.

20 plank 9 feet long, 4 by about 15 inches, for the top of the husk.

2 head-blocks, 7 feet long, 12 by 15 inches, for the wallower shafts to run on. They serve as spurs also for the head-block for the water-wheel shaft.

For the Water and big Cog-Wheel.

1 shaft, 18 feet long, 2 feet diameter.
8 arms for the water-wheel, 18 feet long, 3 by 9 inches.
16 shrouds, 8½ feet long, 2 inches thick, and 8 deep.
16 face boards, 8 feet long, one inch thick, and 9 deep.
56 bucket boards, 2 feet 4 inches long, and 17 inches wide.
140 feet of boards, for soaling the wheel.
3 arms for the cog-wheel, 9 feet long, 4 by 14 inches.
16 cants, 6 feet long, 4 by 17 inches.

For little Cog-wheels.

2 shafts 9 feet long, 14 inches diameter.
4 arms, 7 feet long, 3½ by 10 inches.
16 cants, 5 feet long, 4 by 18 inches.

For Wallowers and Trundles.

60 feet of plank, 3½ inches thick.
40 feet do. 3 inches thick, for bolting gears.

Cogs and Rounds.

200 cogs to be split, 3 by 3, 14 inches long.
80 rounds, do. 3 by 3, 20 inches long.
160 cogs, for bolting works, 7 inches long, and 1 3-4 square: but if they be for a mill with machinery complete, there must be more accordingly.

Bolting Shafts.

1 upright shaft, 14 feet long, 5½ by 5½ inches.
2 horizontal shafts, 17 feet long, 5 by 5 inches.
1 upright do. 12 feet long, 5 by 5 inches.
6 shafts, 10 feet long, 4 by 4 do.

ART. 37.

BILL OF THE LARGE IRONS FOR A MILL OF TWO PAIR OF STONES.

2 gudgeons, 2 feet 2 inches long in the shaft; neck $4\frac{1}{4}$ inches long, 3 inches diameter, well steeled and turned. See plate XII, fig. 16.

2 bands, 19 inches diameter inside, $\frac{3}{4}$ thick, and 3 inches wide, for the ends of the shaft.

2 do. $20\frac{1}{2}$ inches inside, $\frac{1}{2}$ an inch thick, and $2\frac{1}{2}$ inches wide, for do.

2 do. 23 inches do. $\frac{1}{2}$ an inch thick, and $2\frac{1}{2}$ inches wide, for do.

4 gudgeons, 16 inches in the shaft, $3\frac{1}{2}$ inches long, and $2\frac{1}{2}$ inches diameter in the neck for wallower shafts: See fig. 15, plate XXIV.

4 bands, 12 inches diameter inside, $\frac{1}{2}$ an inch thick, and 2 wide, for do.

4 do. 12 inches do. $\frac{1}{2}$ an inch thick and 2 wide, for do.

4 wallower bands, 3 feet 2 inches diameter inside, 3 inches wide and $\frac{1}{4}$ of an inch thick.

4 trundle bands, 2 feet diameter inside, 3 inches wide, and $\frac{1}{4}$ of an inch thick.

2 spindles and rynes; spindles 5 feet 3 inches long from the foot to the top of the necks; cock-heads 7 or 8 inches long above the necks; the body of the spindles $3\frac{1}{4}$ by 2 inches; the neck 3 inches long, and 3 inches diameter: the balance rynes proportional to the spindles, to suit the eye of the stone, which is 9 inches diameter. See plate XII, fig. 1, 2, 3.

2 steps for the spindles, fig. 4.

2 sets of damsel-irons, 6 knockers to each set.

2 bray-irons, 3 feet long, $1\frac{3}{4}$ inch wide, $\frac{1}{2}$ an inch thick: being a plain bar, one hole at the lower, and 5 or 6 at the upper end.

Bill of Iron for the Bolting and Hoisting-works in the common Way.

2 spur-wheel bands, 20 inches diameter from outsides, for the bolting spur-wheel, $\frac{3}{4}$ of an inch wide, and $\frac{1}{4}$ thick.

2 spur-wheel bands 12 inches diameter from outsides, for the hoisting spur-wheel.

2 step gudgeons and steps, 10 inches long, $1\frac{1}{8}$ inch thick in the tang, or square part; neck 3 inches long, for the upright shafts. See plate XXIV, fig. 5 and 6.

2 bands for do. 5 inches diameter inside, $1\frac{1}{4}$ wide, and $1\frac{1}{4}$ thick.

2 gudgeons, 9 inches tang; neck 3 inches long, 1 1-8 square, for the top of the uprights.

8 bands, $4\frac{1}{2}$ inches diameter inside.

1 socket gudgeon, 1 1-8 of an inch thick; tang 12 inches long; neck 4 inches; tenon to go into the socket $1\frac{1}{2}$ inch, with a key-hole at the end. See fig. 8 and 9.

14 gudgeons, necks $2\frac{1}{2}$ inches, tangs 8 inches long, and one inch square, for small shafts and one end of the bolting-reels.

10 bands for do. 4 inches diameter inside, and 1 inch wide.

4 socket-gudgeons, for the 4 bolting-reels, $1\frac{1}{4}$ square; tangs 8 inches: necks 3 inches, and tenons $1\frac{1}{2}$ inch, with holes in the end of the tangs for rivets, to keep them from turning: the sockets 1 inch thick at the mortise, and 3 inches between the prongs. See fig. 8 and 9. Prongs 8 inches long and 1 wide.

8 bands, $3\frac{1}{4}$ inches, and 8 do. 4 inches diameter, for the bolting-reel shafts.

For the Hoisting-wheels.

2 gudgeons, for the jack-wheel, neck $3\frac{1}{2}$ inches, and tang 9 inches long, 1 1-8 square.

2 bands for do. $4\frac{1}{2}$ inches diameter.

2 gudgeons, for the hoisting-wheel, neck $3\frac{1}{2}$ inches, tang 9 inches long, and $1\frac{1}{4}$ inch square.

2 bands, for do. 7 inches diameter.

6 bands for bolting-heads, 16 inches diameter inside, $2\frac{1}{4}$ wide, and 1-6 of an inch thick.

6 do. for do. 15 inches do. do.

N. B. All the gudgeons should taper a little, as the sizes given are their largest part. The bands for shafts should be a little widest at the foremost side to make them drive well; but those for heads should be both sides

equal.—6 picks for the stones, 8 inches long, and 1¼ wide, will be wanted.

ART. 38.

EXPLANATION OF THE PLATES.

PLATE XVII.

Drawn from a scale of quarter of an inch for a foot.

Fig. 1, a big cog-wheel, 8 feet 2 1-3 inches the diameter of its pitch circle; 8 feet 10 1-3 inches from out to out; 69 cogs, 4½ inch pitch.

2, a little cog-wheel, 5 feet 10 1-3 inches the diameter of its pitch circle, and 6 feet 6 inches from out to out, to have 52 cogs, 4¼ pitch.

3, a wallower, 3 feet 1¼ inches the diameter of its pitch circle, and 3 feet 4¼ inches from out to out; 26 rounds, 4½ pitch.

4, a trundle, 1 foot 8 1-3 inches the diameter of its pitch circle, and 1 foot 11 1-3 inches from out to out: 15 rounds, 4¼ inches pitch.

5, the back part of the big cog-wheel.

6, a model of locking 3 arms together.

7, the plan of a forebay, showing the sills, caps, and where the mortises are made for the posts, with a rack at the upper end to keep off the trash.

PLATE XVIII.—*The Ground-plan of a Mill.*

Fig. 1 and 8, bolting-chests and reels, top view.

2 and 4, cog-wheels that turn the reels.

3, cog-wheel on the lower end of a short upright shaft.

5 and 7, places for the bran to fall into.

6, 6, 6, three garners on the lower floor for bran.

9 and 10, posts to support the girders.

11, the lower door to load wagons, horses, &c. at.

12, the step-ladder, from the lower floor to the husk.

13, the place where the hoisting casks stand when filling.

14 and 15, the two meal-troughs and meal-spouts.

16, meal shaking sieve for indian and buck-wheat.

Fig. 17, a box for the bran to fall into from the sieve.
18 and 19, the head-block, and long spur-block, for the big shaft.
20, four posts in front of the husks, called bray posts.
21, the water and cog-wheel shaft.
22, the little cog-wheel and shaft, for the lower stones.
23, the trundle for the burr stones.
24, the wallower for do.
25, the spur-wheel that turns the bolts.
26, the cog-wheel.
27, the trundle, head wallower and bridge-tree, for country stones.
28, the four back posts of the husk..
29, the two posts that support the cross girder.
30, the two posts that bear up the penstocks at one side.
31, the water-wheel 18 feet diameter.
32, the two posts that bear up the other side of the penstock.
33, the head-blocks and spur-blocks, at water end.
34, a sill to keep up the outer ends.
35, the water-house door.
36, a hole in the wall for the trunk to go through.
37, the four windows of the lower story.

PLATE XIX.—*Second Floor.*

Fig 1 and 9, a top view of the bolting-chests and reels.
2 and 10, places for bran to fall into.
3 and 8, the shafts that turn the reels.
4 and 7, wheels that turn the reels.
5, a wheel on the long shafts between the uprights.
6, a wheel on the upper end of the upright shaft.
11 and 12, two posts that bear up the girders of the third floor.
13, the long shaft between two uprights.
14, five garners to hold toll, &c.
15, a door in the upper side of the mill-house.
16, a step-ladder from 2d to 3d floor.
17, the running burr mill-stone laid off to be dressed.
18, the hatchway.
19, stair-way.

Fig. 20, the running country stone turned up to be dressed.
21, a small step-ladder from the husk to second floor.
22, the places where the cranes stand.
24, the pulley-wheel that turns the rolling screen.
25 and 26, the shaft and wheel that turns the rolling-screen and fan.
27, the wheel on the horizontal shaft to turn the bolting-reels.
28, the wheel on the upper end of the first upright shaft.
29, a large pulley that turns the fan.
30, the pulley at the end of the rolling-screen.
31, the fan.
32, the rolling-screen.
33, a step-ladder from the husk to the floor over the water-house.
34 and 35, two posts that support the girders of the 3d floor.
36, a small room for the tailings of the rolling-screen.
37, a room for the fannings.
38, do. for the screenings.
39, a small room for the dust.
40, the penstock of water.
41, a room for the miller to keep his books in.
42, a fire-place.
43, the upper end door.
44, ten windows in the 2d story, 12 lights each.

PLATE XX.

Represents a view of the lower side of a stone mill-house three stories high, which plan will suit tolerably well for a two story house, if the third story be not wanted. Part of the wall supposed to be open, so that we have a view of the stones, running gears, &c.

Line 1 represents the lower floor, and is nearly level with the top of the sills, of the husk and water-house.
2, 3 and 4 the second, third, and fourth floors.
5 and 6 are windows for admitting air under the lower floor.
7 the lower door, with steps to ascend to it, which commonly suits best to load from.

8 the arch over the tail-race for the water to run from the wheel.
9 the water-house door, which sometimes suits better to be at the end of the house, where it makes room to wedge the gudgeon.
10 the end of the water-wheel shaft.
11 the big cog-wheel shaft.
12 the little cog-wheel and wallower, the trundle being seen through the window.
13 the stones with the hopper, shoe and feeder, as fixed for grinding.
14 the meal-trough.

We have an end view of the husk frame—there are thirteen windows with twelve lights each.

PLATE XXI.

Represents an outside view of the water end of a mill-house, and is to show the builders, both masons, carpenters and mill-wrights, the height of the walls, floors, and timbers; places of the doors and windows, with a view of the position of the stones and husk-timbers, supposing the wall open so that we could see them.

Fig. 1, 2, 3, and 4 shows the joists of the floors.
5 represents a fish turning with the wind on an iron rod, which does as well as a weather-cock.
6 the end of the shaft for hoisting outside of the house, which is fixed above the collar-beams above the doors, to suit to hoist into either of them, or either story, at either end of the house, as may best suit.
7 the dark squares, showing the ends of the girders.
8 the joists over the water-house.
9 the mill-stones, with the spindles they run on, and the ends of the bridge-trees as they rest on the brays a a. b b shows the end of the brays, that are raised and lowered by the levers c c, called the lighter-staffs, thereby raising and lowering the running stone.
10 the water-wheel and big cog-wheel.
11 the wall between the water and cog-wheel.
12 the end view of the two side walls of the house.

Plate X is explained in the Preface.

ART. 39.

OF SAW-MILLS—THEIR UTILITY.

They are for sawing timber into all kinds of scantling, boards, laths, &c. &c. are used to great advantage where labour is dear. One mill, attended by one man, if in good order, will saw more than 20 men will with whip-saws, and much more exactly.

Construction of their Water-wheels.

They have been variously constructed; the most simple and useful of which, where water is plenty, and above six feet fall, is the flutter-wheel; but where water is scarce in some cases, and for want of sufficient head in others, to give flutter-wheels sufficient motion, high wheels, double geared, have been found necessary. Flutter-wheels may be made suitable for any head above six feet, by making them low and wide, for low heads; and high and narrow for high ones, so as to make about 120 revolutions, or strokes of the saw, in a minute: but rather than double gear I would be satisfied with 100.

A TABLE

OF THE

DIAMETER OF FLUTTER WHEELS,

From out to outsides, and their width in the clear, suitable to all heads, from 6 to 30 feet.

Head of water.	Diameter.	Width.
ft.	ft. in.	ft. in.
6	2:8	5:6
7	2:10	5:0
8	2:11	4:8
9	3:0	4:3
10	3:1	4:0
11	3:2	3:9
12	3:3	3:6
13	3:4	3:3
14	3:5	3:0
15	3:6	2:9
16	3:7	2:6
17	3:8	2:4
18	3:9	2:2
19	3:10	2:0
20	3:11	1:10
21	4:0	1:9
22	4:1	1:8
23	4:2	1:7
24	4:3	1:6
25	4:4	1:5
26	4:5	1:4
27	4:6	1:3
28	4:7	1:2
29	4:8	1:1
30	4:9	1:0

N. B. The above wheels are proposed as narrow as will well do on account of saving water; but if there is very plenty of it, the wheels may be made wider than directed in the table, and the mill will be more powerful.

Of Gearing Saw-Mills.

Of this I shall say but little, they being expensive and but little used.—They should be geared so as to give the saw about 120 strokes in a minute, when at work in a common log. The water-wheel is like that of another mill, whether of the undershot, overshot, or breast kind; the cog-wheel of the spur kind, and as large as will clear the water. The wallower commonly has 14 or 15 rounds, but so as to produce the right motion. On the wallower shaft is a balance-wheel, which may be of stone or wood: this is to regulate the motion. There should be a good head above the water-wheel to give it a lively motion, else the mill will run heavily.

The mechanism of a complete saw-mill is such as to produce the following effects, viz.

1. To move the saw up and down, with a sufficient motion and power.

2. To move the log to meet the saw.

3. To stop of itself when within 3 inches of being through the log.

4. To draw the carriage with the log back by the power of water ready to enter again.

The mill is stopped as follows, viz. When the gate is drawn the lever is held by a catch, and there is a trigger, one end of which is within half an inch of the side of the carriage, on which is a piece of wood an inch and a half thick, nailed so that it will catch against the trigger as the carriage moves, which throws the catch off of the lever of the gate, and it shuts down at a proper time.

Description of a Saw-mill.

Plate XXIII is an elevation and perspective view of a saw-mill, showing the foundation, walls, frame, &c. &c.

Fig. 0. 1. the frame uncovered, 52 feet long, and 12 feet wide.

Fig 2. the lever for communicating the motion from the saw-gate to the carriage, to move the log. It is 8 feet long, 3 inches square, tenoned into a roller 6 inches

diameter, reaching from plate to plate, and working on gudgeons in them; in its lower side is framed a block 10 inches long, with a mortise in it 2 inches wide, its whole length, to receive the upper end of the hand-pole, having in it several holes for an iron pin, to join the hand-pole to it to regulate the feed, by setting the hand-pole nearer the centre of the roller to give less, and farther off, to give more feed.

Fig. 3. the hand-pole or feeder, 12 feet long, and 3 inches square where it joins the block.

Fig. 4. tapering to 2 inches at the lower end, on which is the iron hand 1 foot long, with a socket, the end of which is flattened, steeled and hardened, and turned down at each side half an inch, to keep it on the rag-wheel.

Fig. 5. the rag-wheel. This has four cants $4\frac{1}{2}$ feet long, 17 by 3 inches in the middle, lapped together to make the wheel 5 feet diameter, is faced between the arms with 2 inch plank to strengthen the laps. The cramp or ratchet-iron is put on as a hoop near 1 inch square, with ratchet-notches cut on its outer edge, about 3 to an inch. On one side of the wheel are put 12 strong pins, nine inches long, to tread the carriage back, when the backing works are out of order. On the other side are the cogs, about 56 in number, 3 inch pitch to gear into the cog-wheel on the top of the tub-wheel shaft, with 15 or 16 cogs. In the shaft of the rag-wheel are 6 or 7 rounds, 11 inches long in the round part, let in near their whole thickness, so as to be of a pitch equal to the pitch of the cogs of the carriage, and gear into them easily: the ends are tapered off outside, and a band drove on them at each end, to keep them in their places.

Fig. 6. the carriage. Is a frame 4 feet wide from outsides, one side 29 feet long, 7 by 7 inches; the other 32 feet long, 8 by 7 inches, very straight and true, the inter-ties at each end 15 by 4 inches, strongly tenoned and braced into the sides to keep the frame from racking. In the under side of the largest piece are set two rows of cogs, 2 inches between the rows, and 9 inches from the fore side of one cog to that of another; the cogs of one

row between those of the other, so as to make $4\frac{1}{2}$ inch pitch, to gear into the rounds of the rag-wheel. The cogs are about 66 in number; shank 7 inches long, 1 3-4 inch square; head 2 3-4 long, 2 inches thick at the points, and $2\frac{1}{4}$ inches at the shoulder.

Fig. 7. the ways for the carriage to run on. These are strips of plank $4\frac{1}{2}$ inches wide, 2 inches thick, set on edge, let $1\frac{1}{2}$ inch into the top of the cross sills, of the whole length of the mill, keyed fast on one side, made very straight both side and edge, so that one of them will pass easily between the rows of cogs in the carriage, and leave no room for it to move sideways. They should be of hard wood, well seasoned, and hollowed out between the sills to keep the dust from lodging on them.

Fig. 8. the fender posts. The gate with the saw plays in rabbets $2\frac{1}{2}$ deep and 4 inches wide, in the fender posts, which are 12 feet long, and 12 inches square, hung by hooked tenons, the front side of the two large cross beams in the middle of the frame, in mortises in their upper sides, so that they can be moved by keys to set them plumb. There are 3 mortises two inches square through each post, within half an inch of the rabbets, through which pass hooks with large heads, to keep the frame in the rabbets: they are keyed at the back of the posts.

Fig. 9. the saw, which is 6 feet long, 7 or 8 inches wide when new, hung in a frame 6 feet wide from the outsides, 6 feet 3 inches long between the end pieces, the lowermost of which is 14 by 3 inches, the upper one 12 by 3, the side pieces 5 by 3 inches, 10 feet long, all of the best dry, hard wood. The saw is fastened in the frame by two irons in form of staples, the lower one with two screw pins passing through the lower end, screwing one leg to each side of the end piece: the legs of the upper one are made into screws, one at each side of the end piece, passing through a broad flat bar that rests on the top of the end piece, with strong burrs 1 3-4 inch square, to be turned by an iron span made to fit them.

These straps are made of flat bars, 3 feet 9 inches long, 3 inches wide, 3-4 thick before turned; at the turn they are 5 inches wide, square, and split, to receive the saw,

and tug-pins, then brought nearer together, so as to fit the gate. The saw is stretched tight in this frame, by the screws at the top, exactly in the middle at each end, measuring from the outside; the top end standing about half an inch more forward than the bottom.

Fig. 10. the forebay of water projecting through the upper foundation wall.

Fig. 11. the flutter-wheel. Its diameter and length according to the head of water, as shown in the table. The floats are fastened in with keys, so that they will drive inward, when any thing gets under them, and not break. These wheels should be very heavy, that they may act as a fly or balance to regulate the motion, and work more powerfully.

Fig. 12. the crank—see it represented by a draught from a scale of 1 foot to an inch—pl. XXIV. fig. 17. The part in the shaft 2 feet 3 inches long, 3¾ by 2 inches, neck 8 inches long 3 thick, and 12 inches from the centre of the neck to the centre of the wrist or handle, which is 5 inches long to the key hole, and 2 inches thick.

The gudgeon at the other end of the shaft is 18 inches in the shaft, neck 3½ long, 2¾ diameter.

The crank is fastened in the same way as gudgeons. See art. 13.

Fig. 12—13. the pitman; which is 3½ inches square at the upper end, 4½ in the middle, and 4 near the lower end; but 20 inches of the lower end is 4½ by 5½, to hold the boxes and key, to keep the handle of the crank tight.

Pitman Irons of an improved Construction.

See plate XXIV. fig. 10, 11, 12, 13, 14. 18. Fig. 10. is a plate or bar, with a hole in each end, through which the upper ends of the lug-pins 11—11 pass, with a strong burr screwed on each, they are 17 inches long, 1 1-8 inch square, turned at the lower end to make a round hole 1 1-8 diameter, made strong round the hole.

Fig. 12. is a large flat link, through a mortise near the lower side of the end of the saw-frame. The lug-pins

pass one through each end of this link, which keeps them close to the gate sides.

Fig. 14 is a bar of iron 2 feet long, 3½ inches wide, ½ inch thick, at the lower end, and 1 1-8 at the upper end. It is split at the top and turned as the fig. to pass through the lug-pins. At fig. 13 there is a notch set in the head of the pitman bar 14, 1½ inch long, nearly as deep as to be in a straight line with the lower side of the side pins made a little hollow, steeled and made very hard.

Fig. 18 is an iron plate 1½ inch wide, half an inch thick in the middle, with 2 large nail-holes in each end, and a round piece of steel welded across the middle and hardened, made to fit the notch in the upper end of the pitman, pl. XXVI. and draw close by the lug-pins, to the underside of the saw-frame and nailed fast. Now, if the bearing part of this joint be in a straight line, the lower end of the pitman may play without friction in the joint, because both the upper and lower parts will roll without sliding, like the centre of a scale beam, and will not wear.

This is by far the best plan for pitman irons. The first set I ever seen or heard of has been in my saw-mill 8 years, doing much hard work, and has not cost three minutes to adjust them; whereas others are frequently very troublesome.

Fig. 14, the tub-wheel for running the carriage back. This is a very light wheel, 4 feet diameter, and put in motion by a motion of the foot or hand, at once throwing it in gear with the rag-wheel, lifting off the hand and clicks from the ratchet, and hoisting a little gate to let water on the wheel. The moment the saw stops, the carriage with the log begins to move gently back again.

Fig. 15, the cog-wheel on the top of the tub-wheel shaft, with 15 or 16 cogs.

Fig. 16, the log on the carriage, sawed part through.

Fig. 17, a crank and windlas to increase power, by which one man can draw heavy logs on the mill, and turn them by a rope round the log and windlas.

Fig. 18, a cant hook for rolling logs.

Fig. 19, a double dog, fixed into the hindmost head-block, used by some to hold the log.

Fig. 20, are smaller dogs to use occasionally at either end.

Fig. 21—22, represents the manner of shuting water on a flutter-wheel by a long open shute, which should not be more perpendicular than an angle of 45 degrees, lest the water should rise from the shute and take air, which would be a great loss of power.

Fig. 23, represents a long, perpendicular, tight shute; the gate 23 is always drawn fully, and the quantity of water regulated at the bottom by a little gate r for the purpose. There must be air let into this shute by a tube entering at a.* These shutes are for saving expense where the head is great, and should be much larger at the upper than lower end, else there will be a loss of power.† The perpendicular ones suit best where a race passes within 12 feet of the upper side of the mill.

OPERATION.

The sluice drawn from the penstock 10, puts the wheel 11 in motion—the crank 12 moves the saw-gate and saw 9 up and down, and as they rise they lift up the lever 2, which pushes forward the hand-pole 3, which moves the rag-wheel 5, which gears in the cogs of the carriage 6, and draws forward the log 16 to meet the saw, as much as is proper to cut at a stroke. When it is within 3 inches of being through the log, the cleet C, on the side of the carriage, arrives at a trigger and lets it fly, and the sluice-gate shuts down: the miller instantly draws water on the wheel 14, which runs the log gently back, &c. &c.

ART. 40.

DESCRIPTION OF A FULLING-MILL.

Fig. 19, plate XXIV, is the penstock, water-gate and spout of an overshot fulling-mill, the whole laid down from a scale of 4 feet to an inch.

Fig. 20, one of the 3 interties, that are framed one end into the front side of the top of the stock-block; the other ends into the tops of the 3 circular pieces that

* The use of this air-tube is shown art. 71, page 161.

† Must be very strong else they will burst.

guide the mallets; they are 6 feet long, 5 inches wide, and 6 deep.

Fig. 21 are the two mallets; they are 4 feet 3 inches long, 21 inches wide, and 8 thick, shaped as in the figure.

Fig. 22 their handles, 8 feet long, 20 inches wide, and 3 thick. There is a roller passes through them, 8 inches from the upper ends, and hang in the hindermost corner of the stock-post. The other ends go through the mallets, and have each on their underside a plate of iron faced with steel and hardened, 2 feet long, 3 inches wide, fastened by screw-bolts, for the tappet-blocks to rub against while lifting the mallets.

Fig. 23 the stock-post, 7 feet long, 2 feet square at the bottom, 15 inches thick at top, and shaped as in the figure.

Fig. 24 the stock where the cloth is beaten, shaped inside as in the figure, planked inside as high as the dotted line, which planks are put in rabbets in the post, the inside of the stock being 18 inches wide at bottom, 19 at top, and 2 feet deep.

Fig. 25 one of the 3 circular guides for the mallets; they are 6 feet long, 7 inches deep, and 5 thick; are framed into a cross sill at bottom that joins its lower edge to the stock-post. This sill forms part of the bottom of the stock, and is 4 feet long, 20 inches wide, and 10 thick.

The sill under the stock-post is 6 feet long, 20 inches wide, and 18 thick. The sill before the stock is 6 feet long, and 14 inches square.

Fig. 26 the tappet-arms, 5 feet 6 inches long, 21 inches each side the shaft, 12 inches wide, and 4 thick. Therh is a mortise through each of them 4 inches wide, the length from shaft to tappet, for the ends of the mallet handles to pass through. The tappets are 4 pieces of hard wood, 12 inches long, 5 wide, and 4 thick, made in the form of half circles pinned to the ends of the arms.

Fig. 27 the overshot water-wheel, similar to other mills.

Fig. 28 one of the 3 sills, 16 feet long, and 12 inches square, with walls under them as in the figure.

OPERATION.

The cloth is put in a loose heap into the stock 24; the water being drawn on the wheel, the tappet-arms lift the mallets alternately, which strike the under part of the heap of cloth, and the upper part is continually falling over, and thereby turning and changing its position under the mallets, which are of the shape in the figure, to produce this effect.

Description of the Drawings of the Iron-works, Plate XXIV.

Fig. 1 is a spindle, 2 the balance-ryne, and 3 the driver, for a mill-stone. The length of the spindle from the foot to the top of the neck is about 5 feet 3 inches; cock-head 8 or 9 inches from the top of the neck, which is 3 inches long, and 3 diameter; blade or body 3½ by 2 inches; foot 1¼ inch diameter; the neck, foot, and top of the cock-head, steeled, turned and hardened.

Fig. 2 the balance-ryne, is sometimes made with 3 horns, one of which is so short as only to reach to the top of the driver, which is let into the stone right under it; the other to reach near as low as the bottom of the driver: but of late are mostly made with 2 horns only, which may be made sufficiently fast by making it a little wider than the eye, and let into the stone a little on each side to keep it steady and from moving sideways. Some choose them with four horns, which fills the eye too much.

Fig. 3 is a driver, about 15 inches long.

Fig 4 the step for the spindle foot to run in. It is a box 6 inches long, 4 inches wide at top, but less at bottom, and 4 inches deep outsides, the sides and bottom half an inch thick. A piece of iron 1 inch thick is fitted to lay tight in the bottom of this box, but not welded; in the midle of which is welded a plug of steel 1½ inch square, in which is punched a hole to fit the spindle-foot a quarter af an inch deep. The box must be tight to hold oil.

Fig. 5 a step-gudgeon for large upright shafts, 16 inches long and two square, steeled and turned at the toe.

Fig. 6 the step for it, similar to 4 but less proportionable.

Fig. 7 is a gudgeon for large bolting-shafts, 13 inches long and 1½ square.

Fig. 8 a large joint-gudgeon, tang 14 inches, neck 5, and tenon 2 inches long, 1½ square.

Fig. 9 the socket part to fit the shaft, with 3 rivet-holes in each.

Fig. 10—14—18 pitman-irons, described art. 39.

Fig. 15 the wallower gudgeon, tang 16 inches, neck 3½ inches long, and 2½ diameter.

Fig. 16 the water-wheel gudgeon, tang 3 feet 2 inches long, neck 4½ inches ditto, 3¼ square.

Fig. 17 a saw-mill crank, described art. 39.

N. B The spindle-ryne, &c. is drawn from a scale of 2 feet to an inch, and all the other irons 1 foot to an inch.

In addition to what is said of Saw-mills, by Thomas Ellicott, I add the following.

Of hanging the Saw.

First, set the fender posts as near plumb every way as possible, and the head-blocks on which the log is to lay, level. Put the saw right in the middle of the gate, measuring from the outsides, with the upper teeth about half an inch farther forward than the lower ones; set it by the gate and not by a plumb line—this is to give the saw liberty to rise without cutting, and the log room to push forward as it rises. Run the carriage forward, so that the saw strike the block—stick up a nail, &c. there—run it back again its full length, and standing behind the saw, set it to direct exactly to the mark. Stretch the saw in the frame, rather most at the edge, that it may be stiffest there. Set it to go, and hold a tool close to one side, and observe whether it touch equally the whole length of the stroke—try if it be square with the top of the head-blocks, else it will not make the scantling square.

Of whetting the Saw.

The edge of the teeth ought to be kept straight, and not suffered to wear hollowing—the teeth set a little out, equal at each side, and the outer corners a little longest—they will clear their way the better. Some whet the under side of the teeth nearly level, and others a little drooping down; but then it will never saw steady—will be apt to wood too much; they should slope a little up, but very little, to make it work steady. Try a cut through the log, and if it comes out at the mark made to set it by, it is shown to be right hung.

Of springing Logs straight.

Some long small logs will spring so much in sawing as to spoil the scantling, unless they can be held straight: to do which make a clamp to bear with one end against the side of the carriage, the other end under the log with a post up the side thereof—drive a wedge between the post and log, and spring it straight; this will bend the carriage side—but this is no injury.

Of moving the Logs, to the Size of the Scantling, &c.

Make a sliding-block to slide in a rabbet in front of the main head-block; fasten the log to this with a little dog on each side, one end of which being round, is drove into a round hole, in the front side of the sliding-block, the other flatted to drive in the log, cutting across the grain, slanting a little out—it will draw the log tight, and stick in the better. Set a post of hard wood in the middle of the main block close to the sliding one, and to extend with a shoulder over the sliding one, for a wedge to be drove under this shoulder to keep the block tight. Make a mark on each block to measure from—when the log is moved the key is driven out. The other end next the saw is best held by a sliding dog, part on each side of the saw pointed like a gouge, with two joint dogs, one on each side of the saw.

Remedy for a long Pitman.

Make it in two parts by a joint 10 feet from the crank, and a mortise through a fixed beam, for the lower end of the upper part to play in, the gate will work more steady, and all may be made lighter.

The feed of a saw-mill ought to be regulated by a screw fixed to move the hand-pole nearer or farther from the centre of the roller that moves it, which may be done as the saw arrives at a knot without stopping the mill.

END OF PART FIFTH.

APPENDIX,

CONTAINING,

Rules for Discovering New Improvements;

EXEMPLIFIED IN IMPROVING

THE ART OF CLEANING AND HULLING RICE,

WARMING ROOMS,

AND

VENTING SMOKE BY CHIMNEYS, &c.

The True Paths to Inventions.

NECESSITY is called the mother of Inventions—but upon inquiry we shall find, that Reason and Experiment bring them forth.—For almost all inventions have been discovered by such steps as the following; which may be taken as a

RULE.

STEP I. Is to investigate the fundamental principles of the theory, and process of the art or manufacture we wish to improve.

II. To consider what is the best plan in theory that can be deduced from, or founded on those principles to produce the effect we desire.

III. Consider whether the theory is already put in practice to the best advantage; and what are the imperfections or disadvantages of the common process improved, and what plans are likely to succeed.

IV. Make experiments in practice to try any plans that these speculative reasonings may propose, or lead to—Any ingenious artist, taking the foregoing steps, will probably be led to improvements on his own art: for we see by daily experience, that every art may be improved. It will, however, be in vain to attempt improvements unless the mind be freed from prejudice, in favour of established plans.

EXAMPLE I.

Take the Art of cleaning Grain by Wind.

BY THE RULE—

STEP I. What are the principles on which the art is founded? Bodies falling through resisting mediums, their velocities are as their specific gravities; consequently the farther they fall the greater will be their distance: on this principle a separation can be effected.

II. What is the best plan in theory? First, make a current of air for the grain to fall through, as deep as possible; then the lightest will be carried farthest, and the separation be more complete at the end of the fall. Secondly, cause the grain with the chaff, &c. to fall in a narrow line across the current, that the light parts may meet no obstruction from the heavy in being carried forward. Thirdly, fix a moveable board edgewise to separate between the good clean grain, and light grain, &c. Fourthly, cause the same blast to blow the grain several times, and thereby effect a complete separation at one operation.

III. Is this theory in practice already? what are the disadvantages of the common process? We find that the farmers' common fans drop the grain in a line 15 inches wide, to fall through a current of air about 8 inches deep, (instead of falling in a line half an inch wide, through a current three feet deep) So that it requires a very strong blast even to blow out the chaff; but garlic, light grains, &c. cannot be got out, they meet so much obstruction from the heavy grains. It has to undergo two or three operations; so that the practice appears no way equal to theory; and appears absurd when tried by the scale of reason.

IV. The fourth step is to construct a fan to put the theory in practice, to try the experiment.* See Art. 83.

EXAMPLE II.

Take the Art of Distillation.

STEP I. The principles on which this art is founded are, evaporation and condensation. The liquid being heated, the spirit it contains being most oily and lightest, evaporates first into steam, which being condensed again into liquid, by cold, is the spirits.

II. The best plan in theory for effecting this, appears as follows: the fire should be applied to the still so as to spend the greatest part of its heat possible, to heat the liquid. Secondly, the steam should be conveyed into a metal vessel of any form that may suit best; which is to be immersed in cold water, to condense the steam; and in order to keep the condenser cold, there should be a stream of water continually entering the bottom and flowing over the top of the condensing tub, the steam should have no free passage out of the condenser, else the strongest part of the liquor may escape.

III. Is this theory already put in practice, and what are the disadvantages of the common process?—1st. Greatest part of the heat escapes up the chimney. 2d. It is almost impossible to keep the grounds from burning in the still. 3dly. The fire cannot be regulated to keep the still from boiling over; therefore we are obliged to run slow: to remedy these disadvantages—First, to lessen the fuel, apply the fire as much to the surface of the still as possible. Enclose the fire by a wall of clay that will not convey the heat away so fast as stone; let in as little air as possibly can be made to keep the fire burning; for the air carries away the heat of the fire. Secondly, to keep the grounds from burning, immerse the still with the liquor into a vessel of water, joining their tops together, then by applying the fire to heat the water in the outside vessel the grounds will not burn,

* This, Timothy Kirk, carpenter, of York-town, is about to do, and claims the invention of the application of the same blast several times, so as to clean the grain completely at one operation; and if the plans are well executed will no doubt excel all others yet made.

and by regulating the heat of the outside vessel the still may be kept from boiling over.

IV. A still of this structure was made by Colonel Alexander Anderson, of Philadelphia, and the experiment tried; but the water in the outside vessel boiled, and being open, the heat escaped thereby, and the liquor in the still could not be made to boil—this appeared to defeat the scheme. But considering that by enclosing the water in a tight vessel, so that the steam could not escape, and that by compressure the heat might be increased, and it passed to the liquor in the still, which now boiled as well as if the fire had been immediately applied to the still. Again, by fixing a valve to be loaded so as to let the steam escape, when arrived to such a degree of heat as to be near boiling over, then the still could not be made to boil over at all.

Thus was an improvement produced, by which he can despatch business in the ratio of 2 to 1, expending fuel in the ratio of 2 to 2½, to produce equal quantities of liquor.—We may bring forward another improvement by considering, that, as we know by experience that compressure above the weight of the atmosphere, keeps the steam from rising from the water, till heated to a certain degree above the boiling heat. We may hence conclude that a compressure less than the atmosphere, will suffer it to rise with a degree less than boiling heat, which suggests the expediency of taking off the pressure of the atmosphere from the liquor in the still, by which means we shall expend less fuel, and the heat need never be so great as to burn the grounds, which may be done by putting the end of the worm into a tight globular vessel of metal, and a cock between it and the condenser; then inject steam from a small boiler, and expel all the air out of this vessel; turn the cock and it will run into the condenser and be condensed. By repeating this, a vacuum may be easily made, and kept up in the worm and top of the still, and the spirits will probably come off with half the heat and fuel usually expended.

This is about to be put in practice to try the experiment. Proved to be an error: much more heat is required to bring off the quantity of spirits. See my work on Steam Engines.

EXAMPLE.

Take the Art of Venting Smoke from Rooms by Chimneys.

STEP I. The principles are:—Heat, by repelling the particles of air to a greater distance, being lighter than cold, will rise above it, forming a current upwards, with a velocity proportional to the degree and quantity of heat, and size of the tube or funnel of the chimney, through which it ascends, and with a power proportional to its perpendicular height, which power to ascend will always be equal to the difference of the weight of a column of rarefied air of the size of the smallest part of the chimney, and a column of common air of equal size and height.

II. What is the best plan in theory for venting smoke, that can be founded on these principles?

1st. The size of the chimney must be proportioned to the size and closeness of the room and size of the fire; because, if the chimney be immensely large and the fire small, there will be no current upwards. And again, if the fire be large, and the chimney too small, the smoke cannot be all vented by it, more air being necessary to supply the fire than can find vent up the chimney, it must spread in the room again, which after passing through the fire and being burnt is suffocating.

2d. The narrowest place in the chimney must be next the fire, and in front of it, so that the smoke would have to pass under it to get into the room: the current will there be greatest, and will draw up the smoke briskly.

3d. The chimney must be perfectly tight, so as to admit no air but at the bottom.

III. The errors in chimneys in common practice are,

1st. In making them widest at bottom.

2d. Too large for the size and closeness of the room.

3d. In not building them high enough above the wind whirling over the tops of houses, that blow down them.

4th. By letting in air any where near the bottom, destroys the current of it at bottom.

IV. The cures directed by the principles and theory are,

1st. If the chimney smoke on account of being too large for the size and closeness of the room, open a door or a window, and make a large fire. But if this be too expensive, make the chimney less at the bottom—its size at the top will not be much injury, but will weaken the power of ascent, by giving the smoke time to cool before it leaves the chimney: the room may be as tight, and fire as small as you please, if the chimney be in proportion.

2d. If it be small at the top and large at the bottom, there is no cure but to lessen it at the bottom.

3d. If it be too small, which is seldom the case, stop up the chimney and use a stove—it will be large enough to vent all the air that can pass through a two inch hole, which is large enough to kindle the fire in a stove.* The chimneys built to put these theories in practice I believe are every where found to answer the purpose. See Franklin's letters on smoky chimneys.

EXAMPLE IV.

Take the Art of Warming Rooms by Fire.

STEP I. The principles of fire are too mysterious to be investigated here; but the effects are,

1st. The fire rarifies the air in the room, which gives us the sensation of heat or warmth.

2d. The warmest part being lightest, rises to the uppermost part of the room, and will ascend through holes (if there be any) to the room above, making it warmer than the one in which the fire is.

3d. If the chimney be open the warm air will fly up it first, leaving the room empty, the cold air will then rush in at all crevices to supply its place, which keeps the room cold.

II. Considering these principles, what is the best plan in theory for warming rooms?

1st. We must contrive to apply the fire to spend all its heat, to warm the air as it comes in the room.

2d. To retain the warm air in the room, and let the coldest out first to obtain a ventilation.

3d. Make the fire in a lower room, conducting the heat through the floor

* The quantity of fuel necessary to warm a room, will ever be in proportion to the quantity of air that ascends the chimney.

into the upper one, and leaving another hole for the cold air to descend to the lower room

4th. Make the room perfectly tight so as to admit no cold air, but all warmed as it comes in.

5th By stopping up the chimney to let no warm air escape up it, but what is absolutely necessary to kindle the fire—a hole of two square inches will be sufficient for a very large room.

6th. The fire may be kindled, by a current of air brought from without, not using any of the air already warmed. If this theory, which is founded on true principles and reason, be compared with common practice, the errors will appear—the disadvantages of which may be evaded.

III. I had a stove constructed to put this theory as fully in practice as possible, and have found all to answer according to theory.

The operation and effects are as follows, viz.

1st. It applies the fire to warm the air as it enters the room, and admits a full and fresh supply, rendering the room moderately warm throughout.

2d. It effectually prevents the cold air from pressing in at the chinks or crevices, but causes a small current to pass outwards.

3d. It conveys the coldest air out of the room first, consequently,

4th. It is a complete ventilator, thereby rendering the room healthy.

5th. The fire may be supplied (in very cold weather) by a current of air from without, that does not communicate with the warm air in the room.

6th. Warm air may be retained in the room any length of time, at pleasure; circulating through the stove, the coldest entering first to be warmed over again.*

7th. It will bake, roast, and boil equally well with the common ten plate stove, as it has a capacious oven.

8th. In consequence of these philosophical improvements, it requires not more than half the usual quantity of fuel.

Description of the Philosophical and Ventilating Stove.

It consists either of three cylindric or square parts, the greatest surrounding the least. See plate X. fig. 1. S F is a perspective view hereof in a square form, supposed open at one side: the fire is put in at F, in the least part which communicates with the space next the outside, where the smoke passes to the pipe 1—5. The middle part is about two inches less than the outside part, leaving a large space between it and above the inner part for an oven, in which the air is warmed, being brought in by a pipe B D between the joists of the floor, from a hole in the wall at B, rising into the stove at D, into the space and oven surrounding the fire, which air is again surrounded by the smoke, giving the fire a full action to warm it, and ascending into the room by the pipe 2. E brings air from the pipe DB to blow the fire. H is a view of the front end plate, showing the fire and oven doors I is a view of the back end, the plate being off, the dark square shows the space for the fire, and the light part the air space surrounding the fire, the dark outside space the smoke surrounding the air; these are drawn on a larger scale. The stove consists of 15 plates, 12 of which join one end against the front plate H.

To apply this stove to the best advantage, suppose fig. 1, plate X. to represent a three or four story house, two rooms on a floor—set the stove S F

* This application was suggested to me by Isaac Garretson, of York-town, on his viewing the stove and considering its principles whilst I had it making.

in the partition on the lower floor, half in each room; pass the smoke pipe through all the stories: make the room very close; let no air enter but what comes in by the pipes A B or CC through the wall at A and G, that it may be the more pure, and pass through the stove and be warmed. But to convey it to any room, and take as much heat as possible with it, there must be an air-pipe surrounding the smoke-pipe, with a valve to open at every floor. Suppose we wish to warm the rooms No. 3—6, we open the valves, and the warm air enters, ascends to the upper part, depresses the cold air, and if we open the holes a—c it will descend the pipes, and enter the stove to be warmed again: this may be done in very cold weather. The higher the room above the stove, the more powerfully will the warm air ascend and expel the cold air. But if the room requires to be ventilated, the air must be prevented from descending, by shutting the little gate 2 or 5, and drawing 1 or 6, and giving it liberty to ascend and escape at A or G—or up the chimney, letting it in close at the hearth. If the warm air be conveyed under the floor, as between 5—6, and let rise in several places, with a valve at each, it would be extremely convenient and pleasant; or above the floor as at 4—several persons might set their feet on it to warm. The rooms will be moderately warm throughout—a person will not be sensible of the coldness of the weather.

One large stove of this construction may be made to warm a whole house, ventilate the rooms at pleasure, bake bread, meat, &c.

These principles and improvements ought to be considered and provided for in bulding.

EXAMPLE V.

Take the Art of Hulling and Cleaning Rice.

STEP I. The principles on which this art may be founded will appear by taking a handful of rough rice, and rubbing it hard between the bands —the hulls will be broken off, and by continuing the operation the sharp texture of the outside of the hull (which through a magnifying glass appears like a sharp fine file, and no doubt is designed by nature for the purpose) will cut off the inside hull, the chaff being blown out, will leave the rice perfectly clean, without breaking any of the grains.

II. What is the best plan in theory for effecting this?—See the plan proposed, represented plate X. fig. 2.—explained art. 103.

III. The disadvantages of the old process are known to those who have it to do.

EXAMPLE VI.

To Save Ships from Sinking at Sea.

STEP I. The principles on which ships float, is the difference of their specific gravities from that of the water, bulk for bulk—sinking only to displace water equal in weight to the ship; therefore, they sink deeper in fresh than salt water. If we can calculate the cubic feet a ship displaces when empty it will show her weight, and subtracting that from what she displaces when loaded, shows the weight of her load, each cubic foot of fresh water being 62,5lb. If an empty rum hogshead weigh 62,5lb. and measure 15 cubic feet, it will require 875lb. to sink it. A vessel of iron,

&c. filled with air, so large as to make its whole bulk lighter than so much water, will float, but if the air be let out and filled with water, will sink. Hence we may conclude that ships, loaded with any thing that will float, will not sink, if filled with water; but if loaded with any thing specifically heavier than water, will sink as soon as filled.

II This appears to be the true theory—How is it to be put in practice, in case a ship springs a leak, that gains on the pumps?

III. The mariner who understands well the above principles and theory, will be led to the following steps.

1st. To cast overboard such things as will not float, and carefully to reserve every thing that will float, for by them the ship may be at last buoyed up.

2d. Empty every cask or thing that can be made water-tight, and put them in the hold and fasten them down under the water, filling the vacancies between them with billets of wood; even the spars and masts may be cut up for this purpose in desperate cases, which will fill the hold with air and light matter, and as soon as the water inside is level with that outside, no more will enter. If every hogshead buoy up 875lb. they will be a great help to buoy up the ship, (but care must be taken not to put the empty casks too low, which would overset the ship) and she will float, although half her bottom be torn off. Mariners, for want of this knowledge, often leave their ships too soon, taking to their boat, although the ship is much the safest, and does not sink for a long time after being abandoned—not considering, although the water gain on their pumps at first, they may be able to hold way with it when risen to a certain height in the hold, because the velocity with which it will enter, will be in proportion to the square root of the difference between the level of the water inside and outside—added to this, the fuller the ship the easier the pumps will work, therefore they ought not to be too soon discouraged.

EXAMPLE VII.

Take the Art of Preserving Fruits, Liquors, &c. from Putrefaction and Fermentation.

STEP I. What are the principles of putrefaction and fermentation? By experiments with the air-pump it has been discovered that apples, cherries, &c. put in a tight vessel, having the air pumped out, will keep their natural fresh bloom for a long time. Again, by repeated experiments it is proved things frozen will neither putrify nor ferment while in that state. Hence we may conclude that air and heat are the principles or moving causes of putrefaction and fermentation.

II. What plans in theory are most likely to succeed? By removing the causes we may expect to evade the effect.

1. Suppose a cistern in a cellar be made on the side of a hill, and supplied by a spring of cold water running in at the top, that can be drawn off at the bottom at pleasure. If apples, &c. be put in tight vessels, and the air pumped out, and beer, cider, &c. be put in this cistern, and immersed in water, will they putrify or ferment? May not the experiment succeed in an ice-house, and fruits be conveyed from one country to another in glass or metal vessels made for the purpose, with the air pumped out and hermetically sealed.

In support of this hypothesis, a neighbour of mine told me, he filled a rum hogshead in the fall full of apples at the bung, bunged it tight, and in

the spring found them all sound; another, when a boy, buried a hollow gum bee-hive full of apples, trampled the earth tight about them, opened them when the wheat began to ripen, and found them all sound, but leaving them, returned in a day or two, and found them all rotten.*

For those who Read to have Leisure.

BY the right use of Natural Philosophy and Reason, aided by Experiments, many improvements might be made that would add much to the conveniences and comforts of life. But the great obstacle is the expense of experiments, in reducing theory to practice, which few will risk. For when a man attempts to make any improvements, he is sure to be ridiculed until he succeeds, and then the invention is often depreciated.—Dr. Franklin said—that "a man's useful inventions subject him to insult, robbery, and abuse"—but this I have as yet experienced only from two or three individuals from whom it was least to be expected. I am firmly persuaded, that if, in any country, the small sum of ——— dollars annually, was assigned to reduce to practice probable theories, the arts would rise in improvement beyond any precedent that history can evince; and the power and wealth of the nation in proportion.—For a long list of inventions in theory might be given, that offer fair to be very useful in practice, that lie dormant until the inventor can make experiments with convenience, to reduce them to practice—many of which, no doubt, will die with the inventors.

Sensible of the expense, time, labour, and thought, that this (though small) work has cost me, and hoping it may be well received by, and prove serviceable to, my country—I wait to see its fate; and feel joy in being ready to say—FINIS.

* Much contained in this Appendix is to be found in different authors; and several things, which I thought had originated with myself, have been treated of by Dr. Franklin.

COMMUNICATION.

The following Essay on Saw-Mills, &c. I received from WILLIAM FRENCH, *Mill-wright, Burlington county, (New Jersey.) since I concluded, and fearing I may not have another opportunity, I publish it.*

SAW-MILLS have been much improved in this state, for low-heads. Mills with two saws, with not more than 7 feet head and fall, have sawed 5 and 6 hundred thousand feet of boards, plank, and scantling, in one year. If the water be put on the wheel in a proper manner, and the wheel of a proper size, (as by the following table) the saw will strike between 100 and 130 strokes in a minute: see fig. 1, plate XIV. The lower edge of the breast-beam B to be 3-4 the height of the wheel, and one inch to a foot, slanting up stream, fastened to the penstock-posts with screw-bolts, (see post A) circled out to suit the wheel C; the fall D circled to suit the wheel and extended to F, 2 inches above the lower edge of the breast-beam, or higher, according to the size of the throat or sluice E. with a shuttle or gate sliding on FE, shutting against the breast-beam B: then 4 buckets out of 9 will be acted on by the water. The method of fastening the buckets or floats is, to step them in starts mortised in the shaft—see start G—9 buckets in a wheel 4½ inches wide, see them numbered 1, 2, &c.

Fig. 2, is the go-back, a tub-wheel. Its common size is from 4½ to 6 feet diameter, with 16 buckets. The water is brought on it by the trunk H. The bucket I is made with a long tenon so as to fasten it with a pin at the top of the wheel.

TABLE

Of the Dimensions of Flutter-wheels.

Head 12 feet.	Bucket 5 feet.	Wheel 3 feet.	Throat 1 3-4 inch.
11	5 1-2	3	2
10	6	3	2 1-8
9	6 1-2	2 10 inches	2 1-4
8	7	2 9	2 1-2
7	7 1-2	2 8	3 1-4
6	8	2 7 p.	3 1-2
5	9	2 6	3 3-4

N. B. The crank about 11 inches, but varies to suit the timber.

The Pile Engine.

Fig. 3, a simple machine for driving piles in soft bottoms for setting mill-walls or dams on. It consists of a frame 6 or 7 feet square, of scantling, 4 by 5 inches, with 2 upright posts 2 inches apart, 10 or 12 feet high, 3 by 3 inches, braced from top to bottom of the frame, with a cap on top 2 feet long, 6 by 8 inches, with a pulley in its middle, for a rope to bend over fastened to a block I, called a tup, which has 2 pieces 4 inches wide between the uprights, with a piece of 2 inch plank T, 6 inches wide, framed on the ends, so as to slide up and down the upright posts S. This machine is worked by 4 or 6 men, drawing the tup up by the sticks fastened to the end of the rope K, and letting it fall on the pile L: they can strike 30 or 40 strokes by the swing of their arms in a minute.

Of building Dams on Soft Foundations.

The best method is to lay 3 sills across stream, and frame cross sills in them up and down stream, setting the main mud-sills on round piles, and pile them with 2 inch plank, well jointed and drove close together edge to edge, from one to the other end. By taking one corner off the lower end of the plank will cause it to keep a close joint at bottom, and by driving an iron dog in the mud-sill, and a wooden wedge to keep it close at the top end will hold it to its place when the tup strikes. It is necessary to pile the outside cross sills also in some bottoms, and to have wings to run 10 or 12 feet into the bank at each side; and the wing-posts 2 or 3 feet higher than the posts of the dam, where the water falls over, planked to the top N N, and filled with dirt to the plate O.

Fig. 4, is a front view of the breast of the tumbling-dam.

Fig. 5, is a side view of the frame of the tumbling-dam, on its piling a b c d e and f g h is the end of the mud-sills. The posts k are framed into the main mud-sills with a hook tenon, leaning down stream 6 inches in 7 feet, supported by the braces l l, framed in the cross sills I; the cross sills I to run 25 feet up and down stream, and be well planked over; and the breast-posts to be planked to the top (see P, fig. 4,) and filled with dirt on the upper side, within 12 or 18 inches of the plate O; (see Q, fig. 5,) slanting to cover the up stream ends of the sills 3 or 4 feet deep: R represents the water.

When the heads are high it is best to plank the braces for the water to run down, but if low, it may fall perpendicularly on the sheeting.

I THINK it my duty to embrace this opportunity, once more to attempt at drawing the attention of my fellow-citizens, to the most ruinous error that the supreme legislature of my country has committed, viz. The laws do not protect the inventors of useful improvements in the arts, in the exclusive enjoyment of the fruits of their labour, for a sufficient length of time, nor afford them any adequate compensation, but make them common

to all at the end of 14 years; a time barely sufficient to mature (in this country) any useful improvement. The consequence is, the inventor is deluded by the name of a patent, and his hopes raised by the accounts he has heard of *the success of inventors in England*, and he makes great exertions and sacrifices to mature, and introduce into use, his improvements; but just as he begins to receive compensation his patent expires, his sanguine hopes are all blasted, he finds himself ruined, and conceives that he has been robbed by law, is thrown into despair, and tempted to deem the precious gift of God (rendering him useful to his country) as a curse; his children that may receive the same gift, bury their talents to shun the danger. Thanks to the Divine Disposer of Events, I have narrowly escaped the worst part of this general fate, having had prudence sufficient to suppress (with much difficulty) my great desire of putting into operation the many useful improvements and discoveries that opened clearly on my mind, so far as to attend to carrying on some regular business for the support of my family, and defraying the expense of my experiments, at the same time that my mind was principally employed in the investigation of principles, and inventing useful improvements. I am however free to declare, that all my study, labour, and time expended during the most vigorous half of my life, in making new inventions, &c. I account as lost to myself and family, excepting the time, &c. expended in compiling and publishing this work, the exclusive right of selling which, is by law secured to me for a second term of 14 years. Two years ago I totally relinquished all pursuit of new improvements, and there is nothing more irksome to me at present, than to be troubled with the description of any proposed new improvements, or to be asked for my opinion or advice concerning them; and I do request the reader, to refrain from intruding in the least on my time in that way, either by written or verbal communications, and I do further declare that I do verily believe, that had the laws been such as to ensure adequate compensation, I could in the time already past, have invented and introduced into use other improvements that would have proved ten times as beneficial to my country, as all those which I have accomplished; but I have been forced to bury my talent with disgust; and have bound in a bundle the drawings and specifications of my inventions, which I have discovered and matured, ready for putting into operation, at the expense of the most intense study and labour of the mind, resolving never to open them, until the laws make it my interest, or their own, to do so; because a patent in this country is not yet worth the expense of obtaining it.

If I did believe that these declarations would only tend to damp the ardour of the American genius, far would it be from me to make them, (in this I may indeed have erred:) but looking forward to futurity I contemplate a contrary effect; (worse the case cannot be made—the ardour of all prudent men has long ago been sufficiently damped, to prevent them from engaging in such pursuits.) Nothing but such a statement of real facts, in plain truth, will rouse the attention of our legislators to a revision of the laws, so as to protect inventors, as well as other classes of the community, in the enjoyment of the fruits of their labours, for a sufficient length of time, to remunerate them for their time and labour, and reward them for their perseverance and ingenuity, in proportion to the benefits they render their country; which alone can inspire them with renewed hope, and give new spring to genius; for it is absurd to suppose that any prudent man will labour for property which he must surrender by law, often before he can fully acquire it, or that expensive experiments should be made without hopes of reward. But if congress will extend the patent term to a period that will ensure adequate compensation, and change the present road to ruin and disgrace, (in which none but the imprudent will walk,) to a path leading to wealth and honour, they will soon see many prudent, inge-

nious men walking therein; and the arts will improve with a progress more rapid than hitherto known in any country, and arrive at a greater degree of perfection in half a century, than in a thousand years under the present discouraging system of legal robbery. Then, instead of discoveries being suppressed, they will be put in operation, and the good people will receive the benefits.

I wish not to be understood to have relinquished the pursuit of improvements on the business I may follow, or in the application of my new principle to steam engines, which I have patented; no, this invention is already accomplished, and I am striving to make the best of it during my patent term—I make steam engines which will work with a power of 100 lbs. to the inch area of the work piston; one of eight inches diameter to carry a load of 5000 lb. when required in extraordinary cases. This is the only principle which will apply to propel boats against the current of the Mississippi by steam, and it may be much improved on in its application for that purpose; all attempts without it will fail to be useful, because there is no other principle in nature left, that will serve as a substitute. When those improvements shall be made in the application of this principle, and shall be put in full operation to navigate that great commercial river, then will the absurdity of that penurious system, which has already kept back this great and useful discovery for upwards of twenty years, most glaringly appear. Let a calculator sit down to compute the annual benefits that will arise to the people, and he will be astonished at the many millions of dollars that will appear as the result. This calculation I refrain from stating, because I believe, that most of my readers would suppose me deranged. The truth will not bear to be told in this case, even to those whose local situation is such, that they would be most benefitted.

For a full explanation of my improvement on steam engines, see my new work, entitled, "The Abortion of the Young Steam Engineer's Guide." Price 125 cents. I am well prepared to construct steam engines, on short notice for those who may want them: they will serve as a substitute for water falls, with great advantage, where fuel is plenty. I have established works for the purpose, consisting of an iron foundry, steam engineer's shop, mould-maker's shop, steam mill for turning and boring heavy iron work, and a blacksmith's shop, all connected: Also, a mill-stone manufactory—and am prepared to execute all orders that I may receive in either of the above lines, especially for engine and mill-works, of either cast or wrought iron. Apply at Mars's Works, Philadelphia.

THE END.

Plate I.

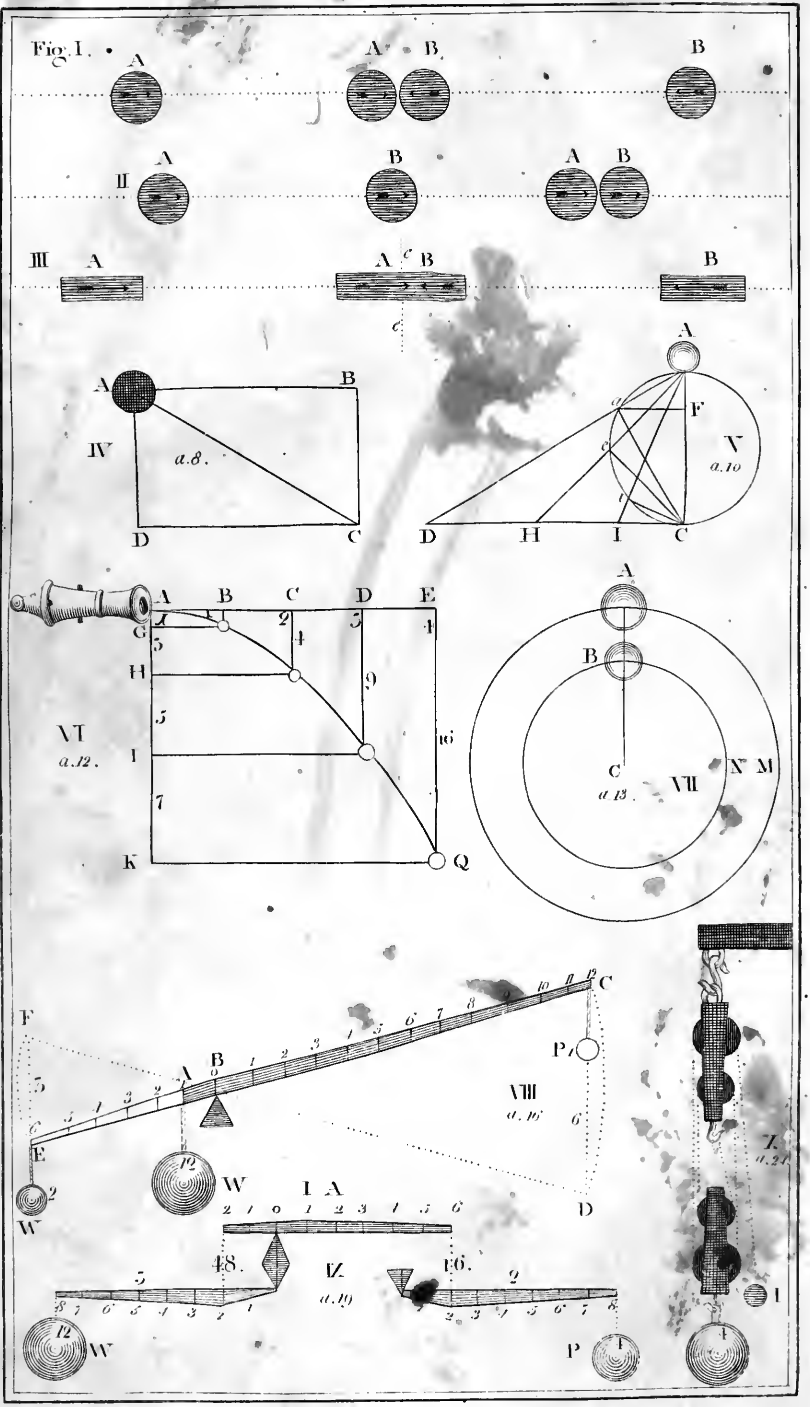

Fig. I.
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Plate II.

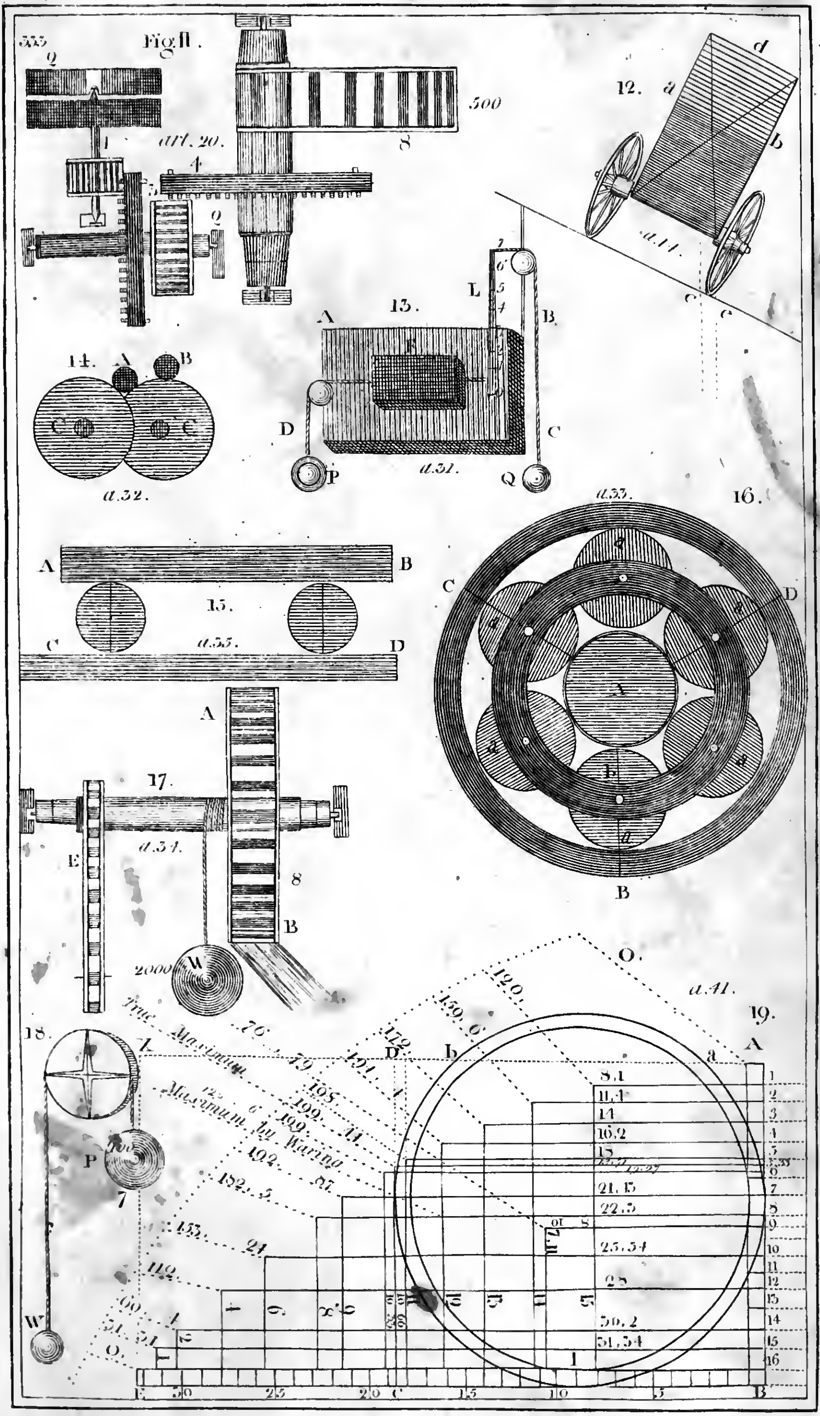

Fig. II.
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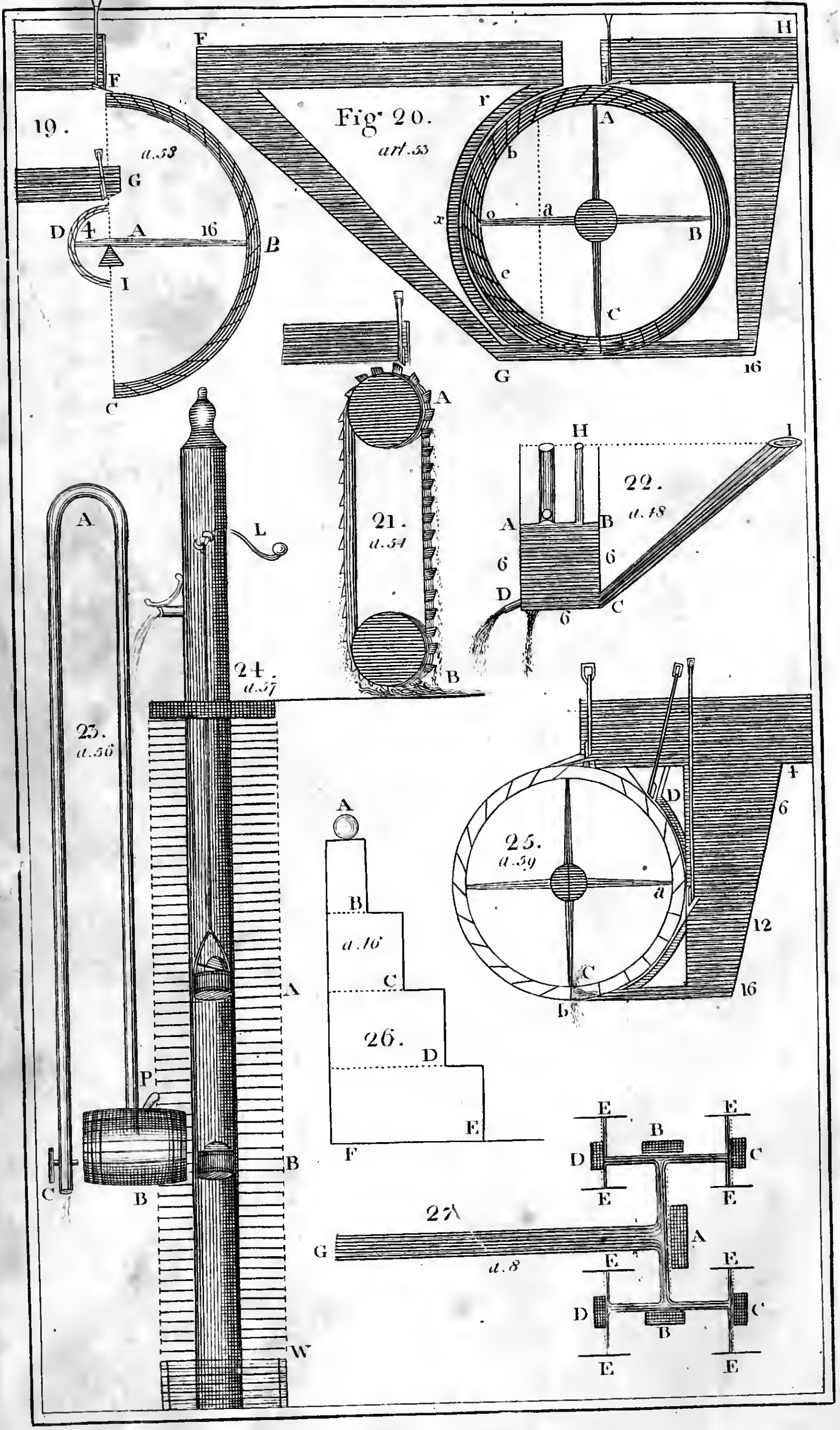
19.
a. 53
Fig. 20.
art. 53
21.
a. 54
22.
a. 48
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24.
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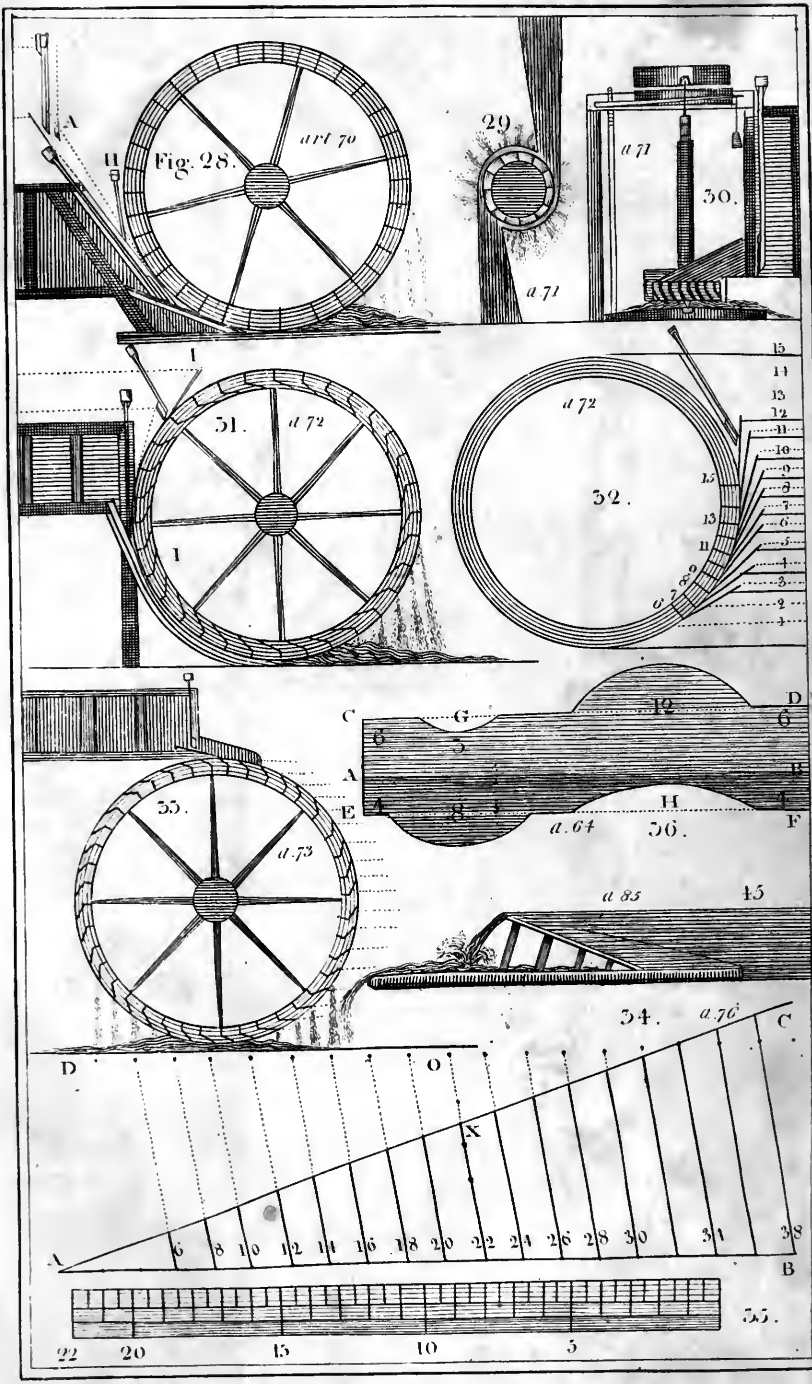
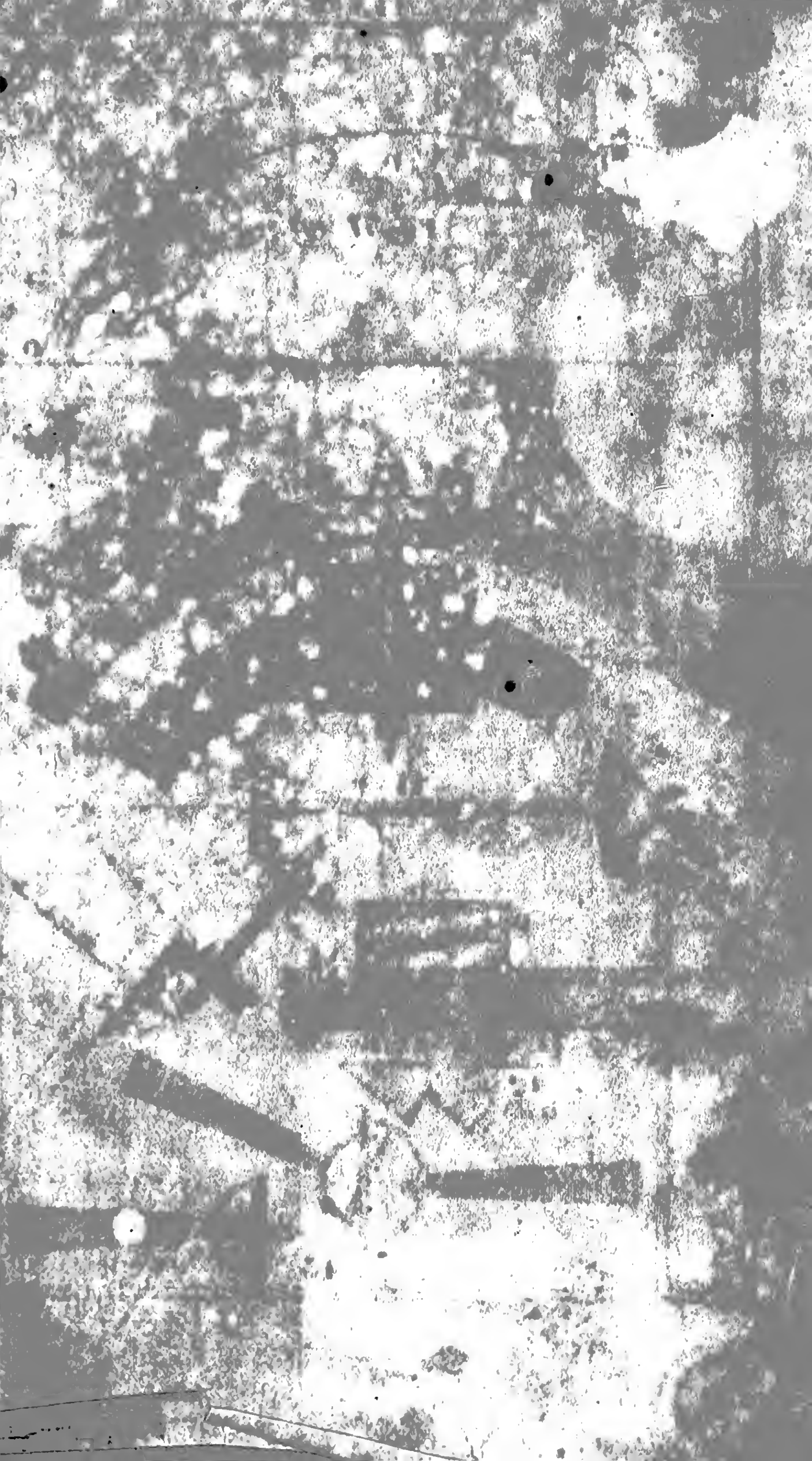
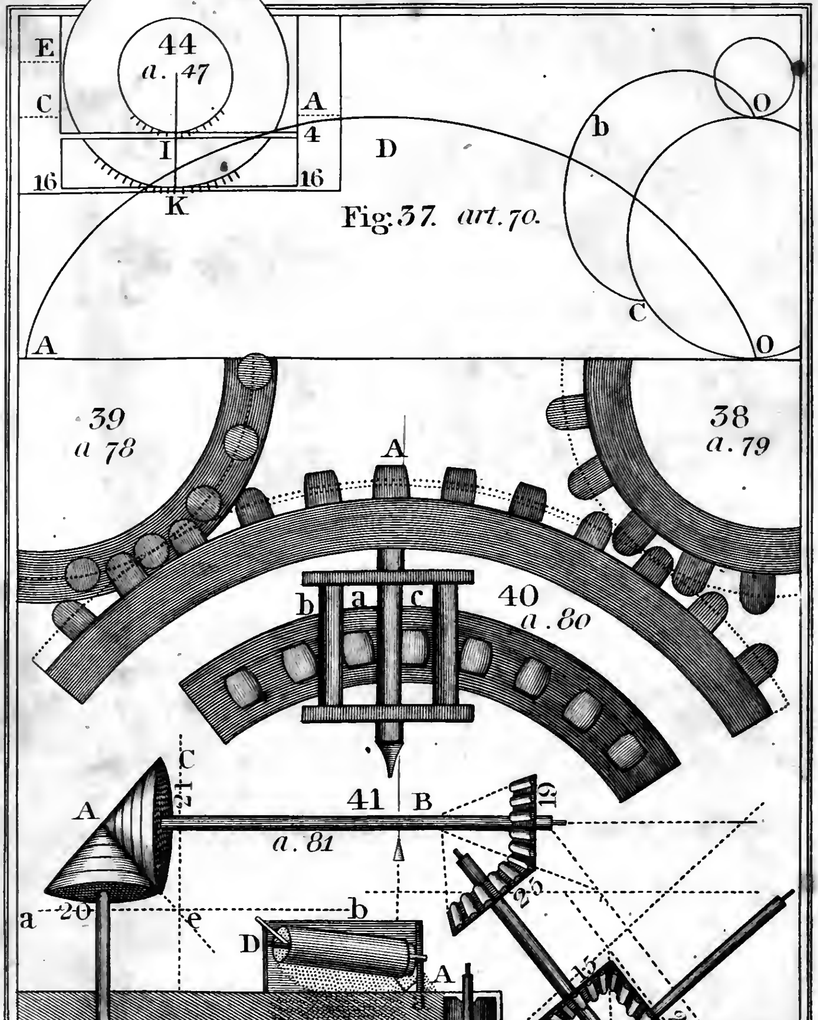
a. 59
26.
a. 16
27
a. 8

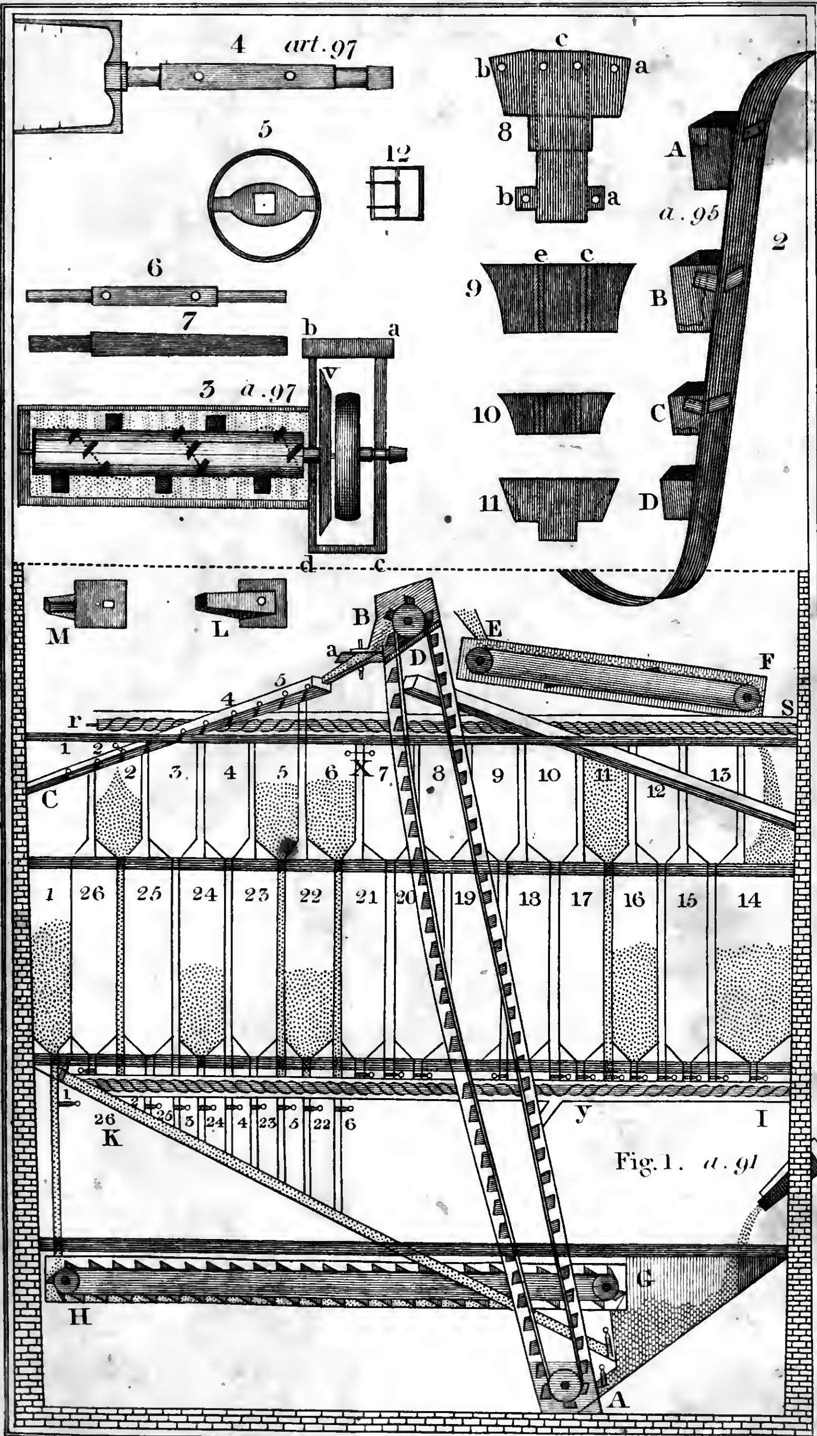
Plate. IV.







Young & Delleker Sc.



Young & Delleker Sc.

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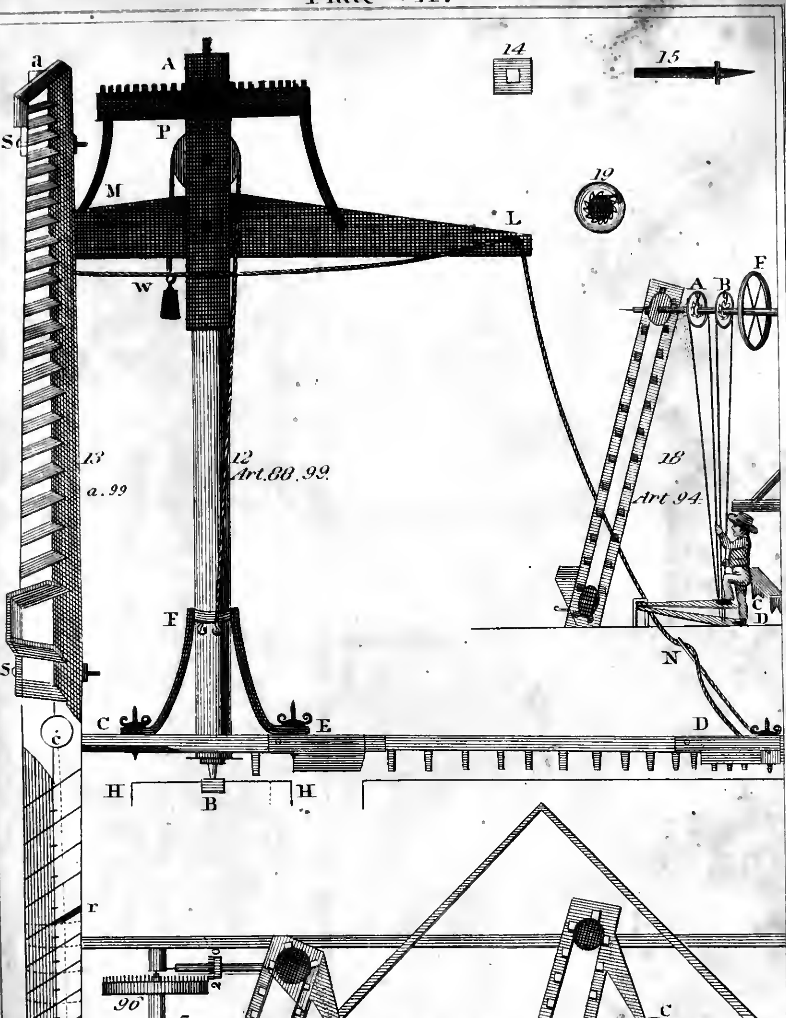

J. Prager Sc.

page 210

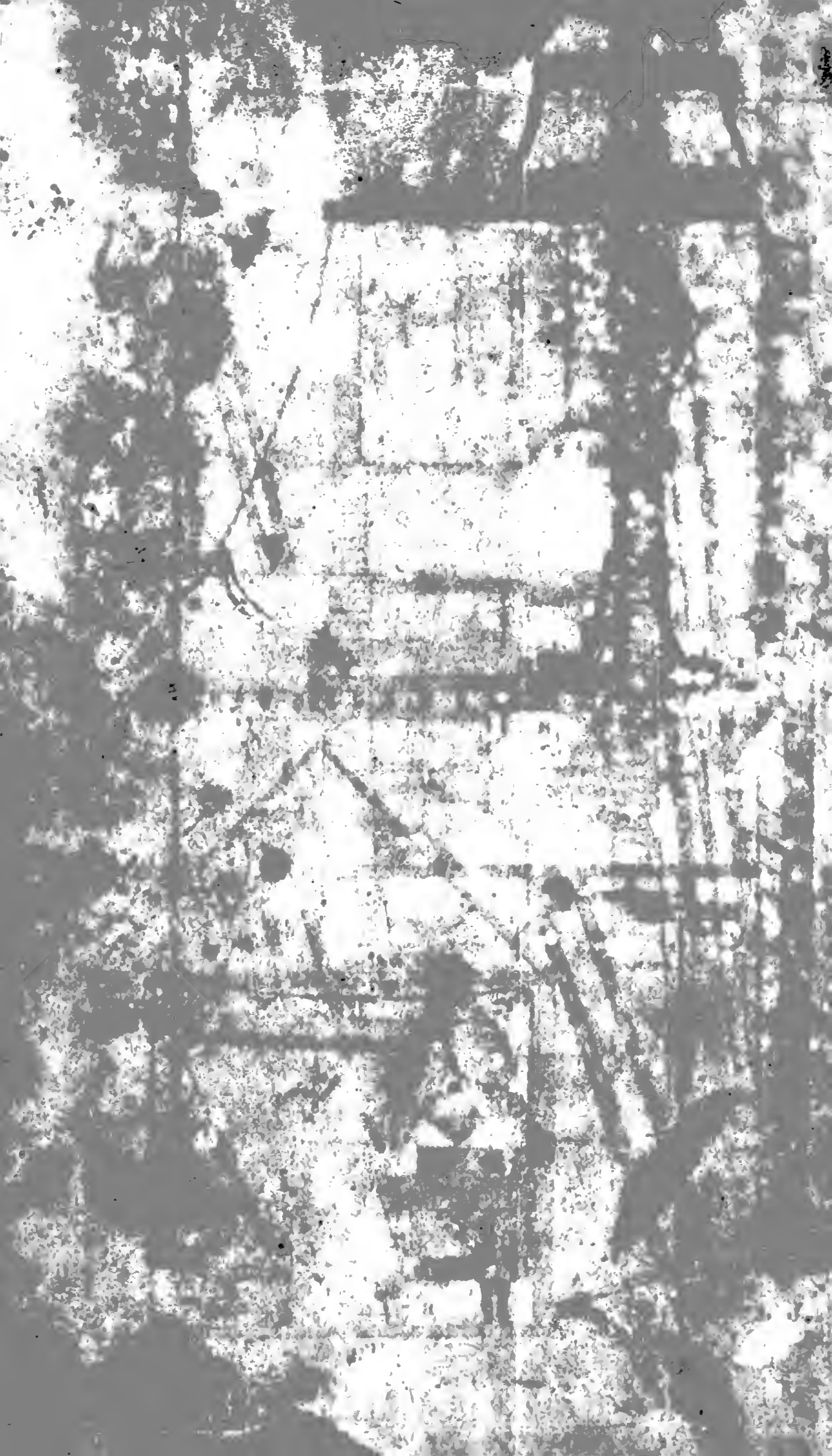

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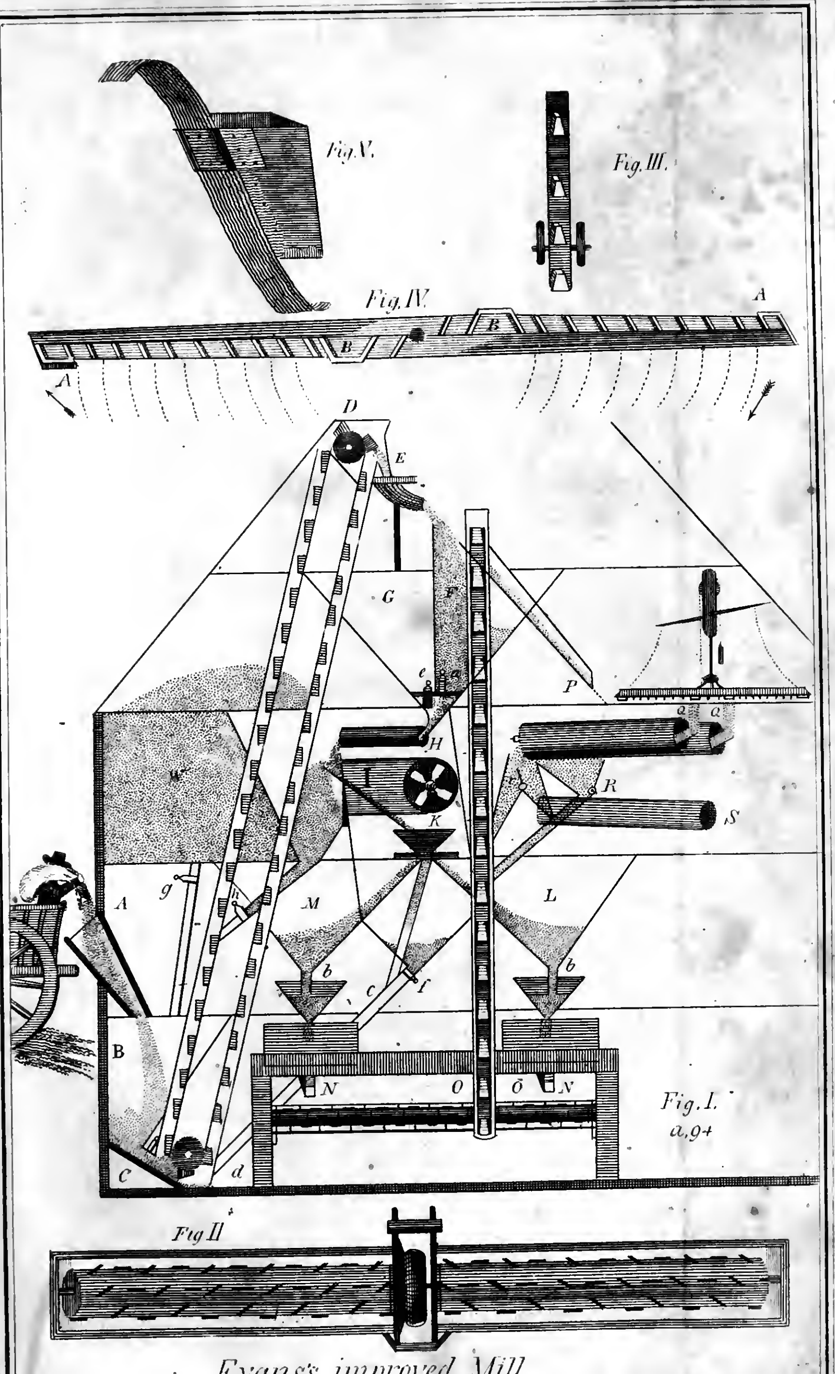
Plate. IX.



Evans's. improved Mill.

Plate. X.

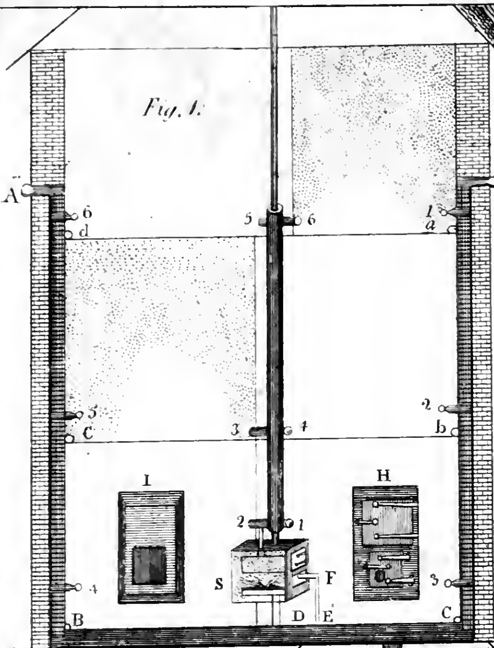


Fig. 1.
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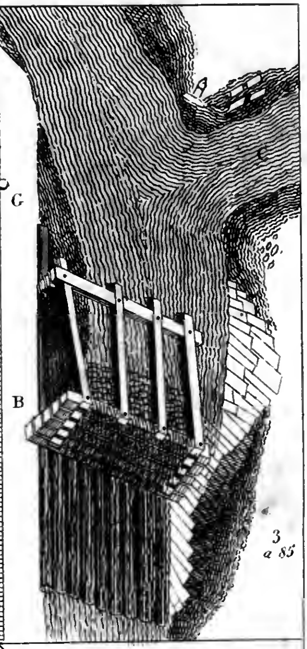
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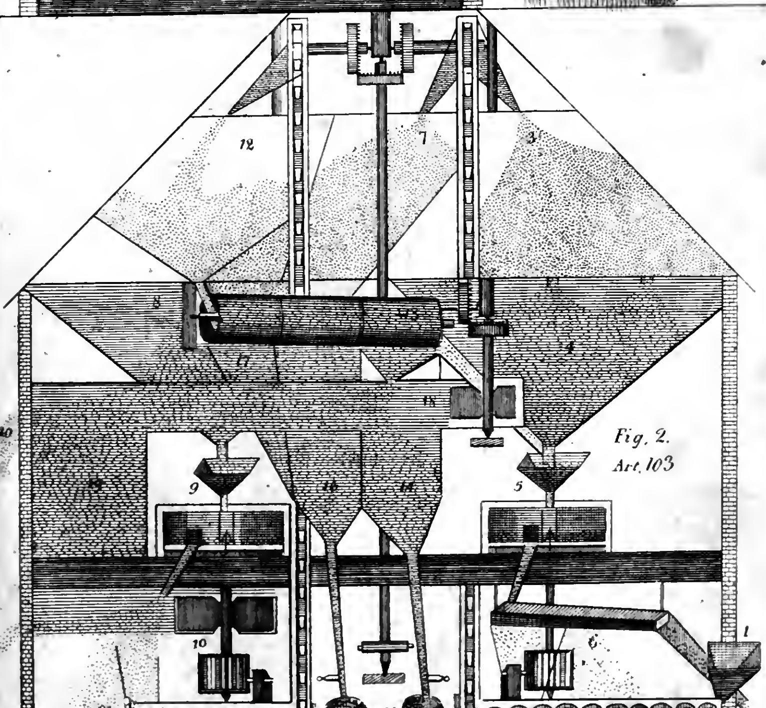
12
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Fig. 2.
Art. 103
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Plate XI.

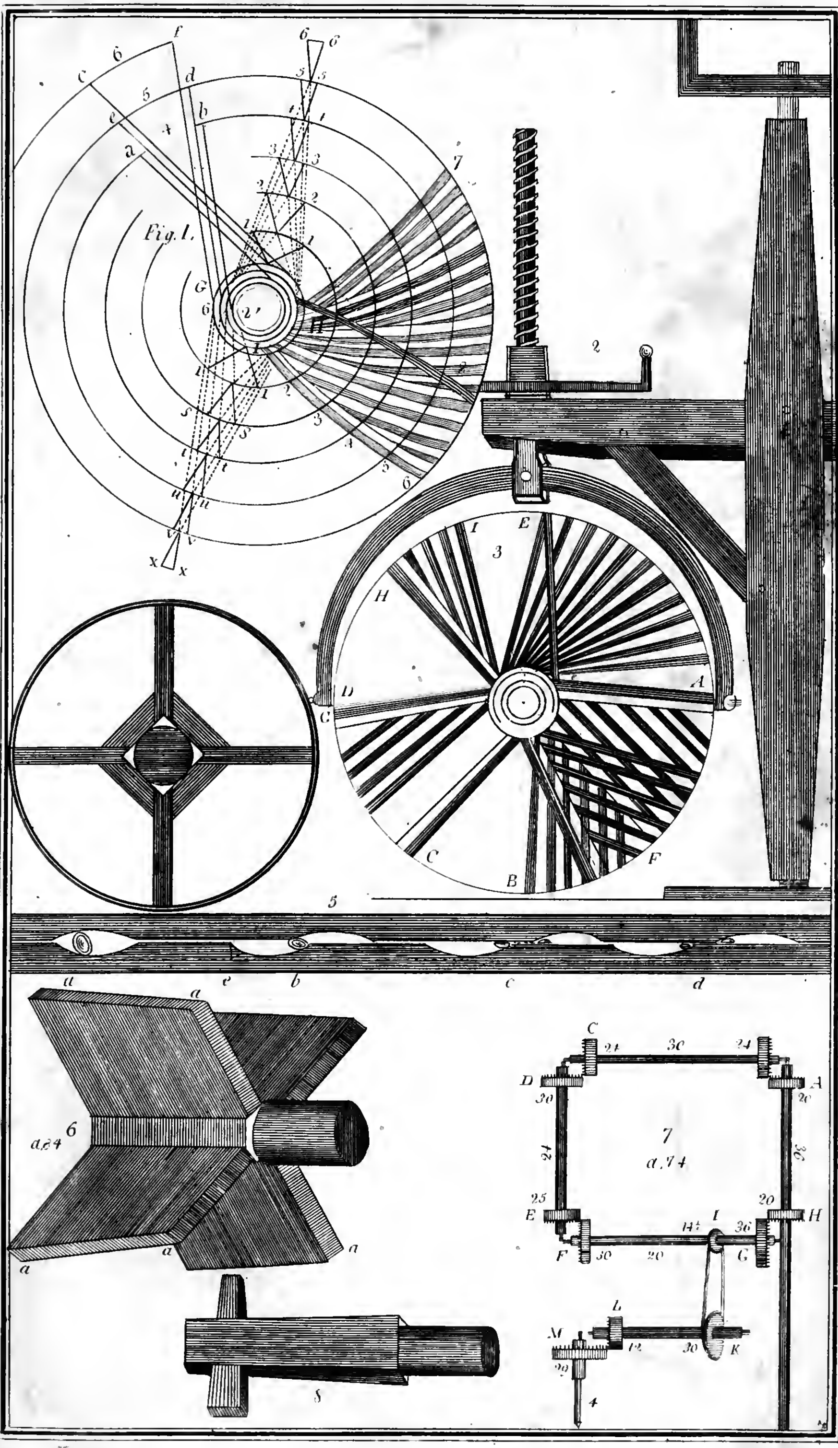


Plate. XII.

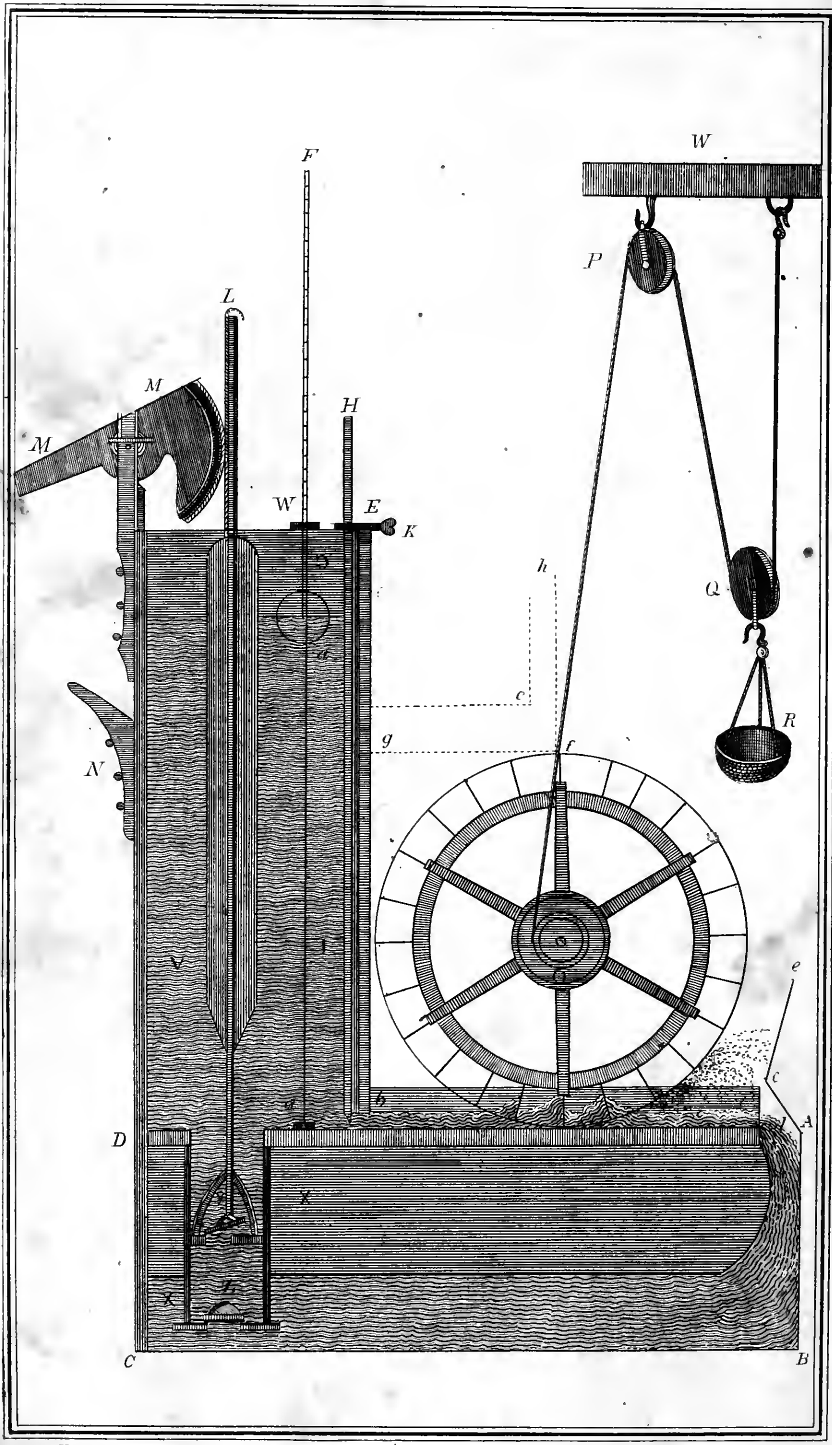


Plate XIII.

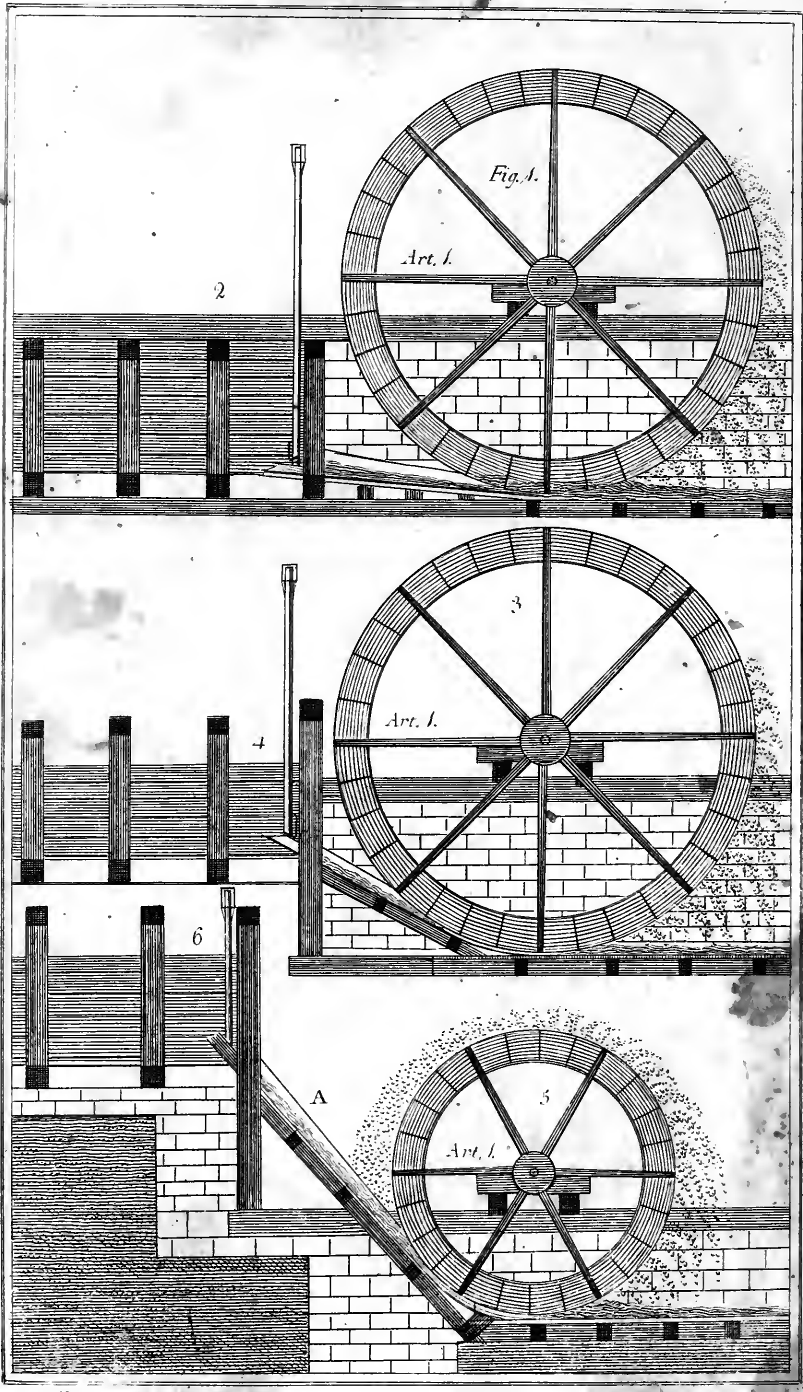
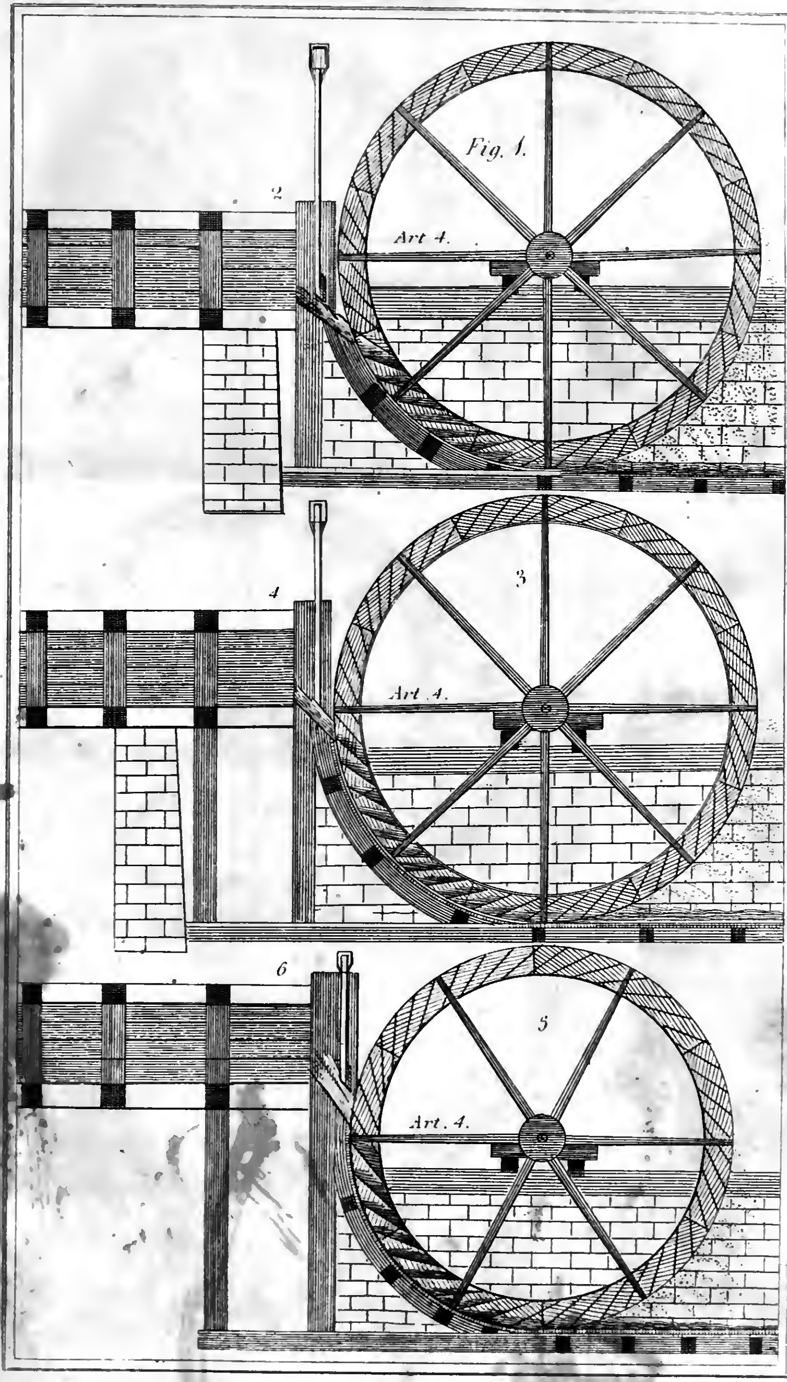
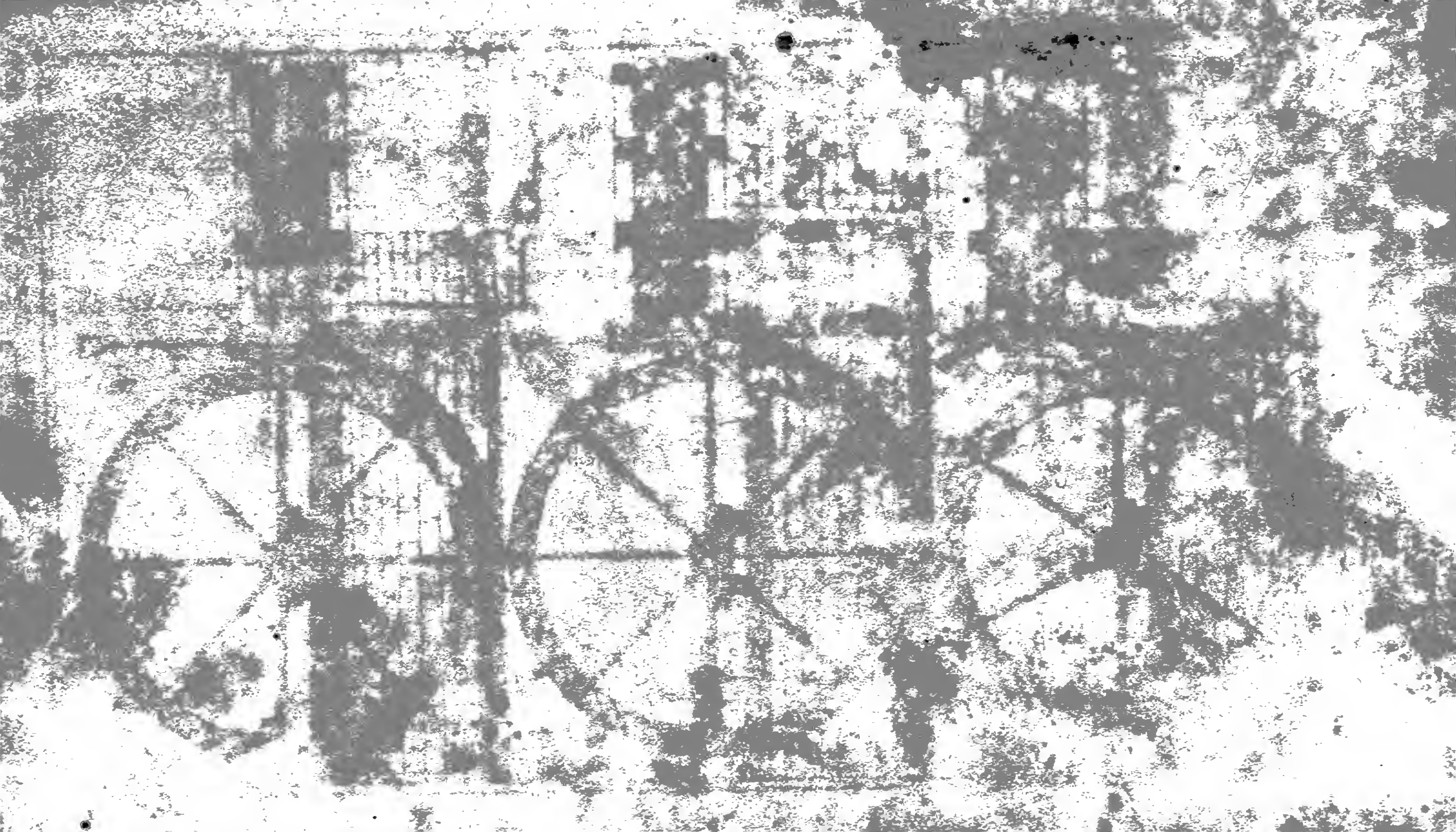


Plate . XIV.





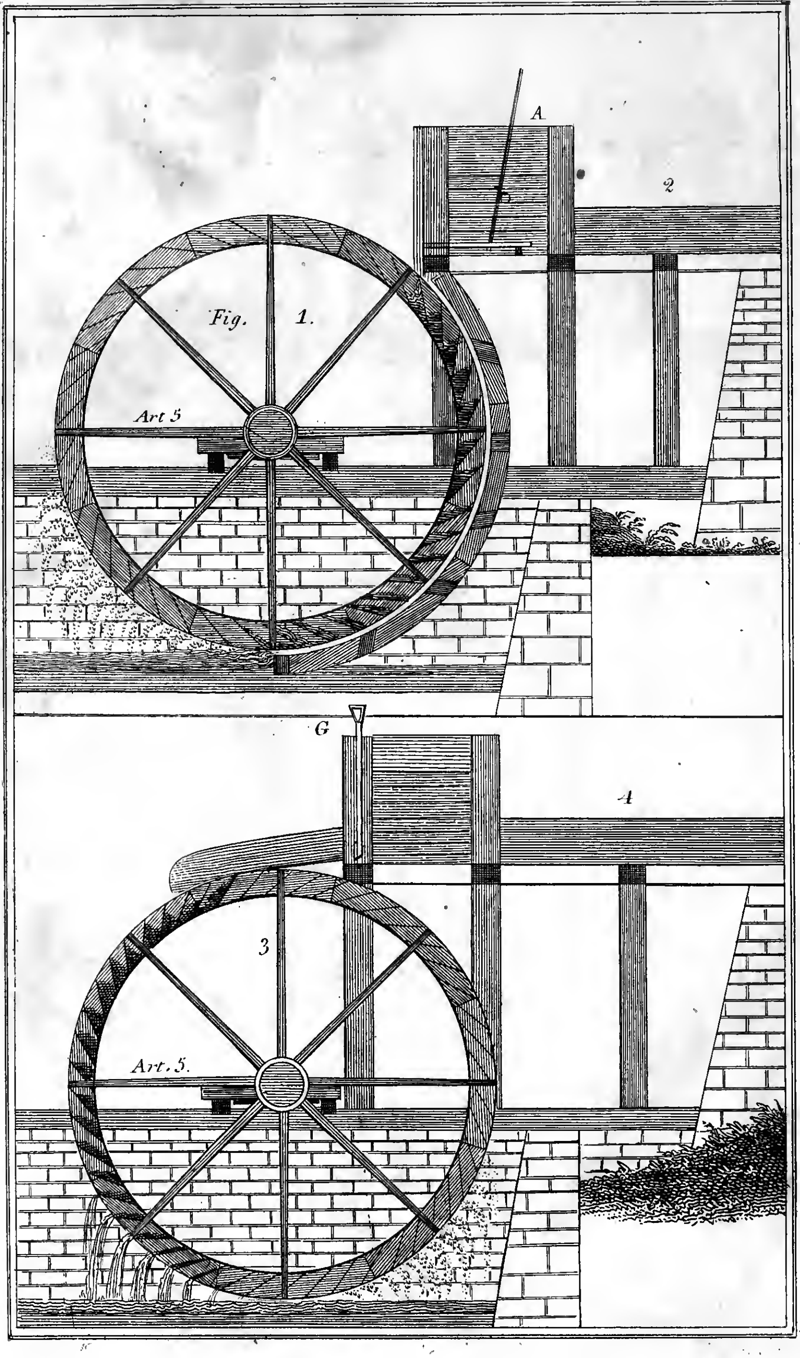

A
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Fig. 1.
Art 5
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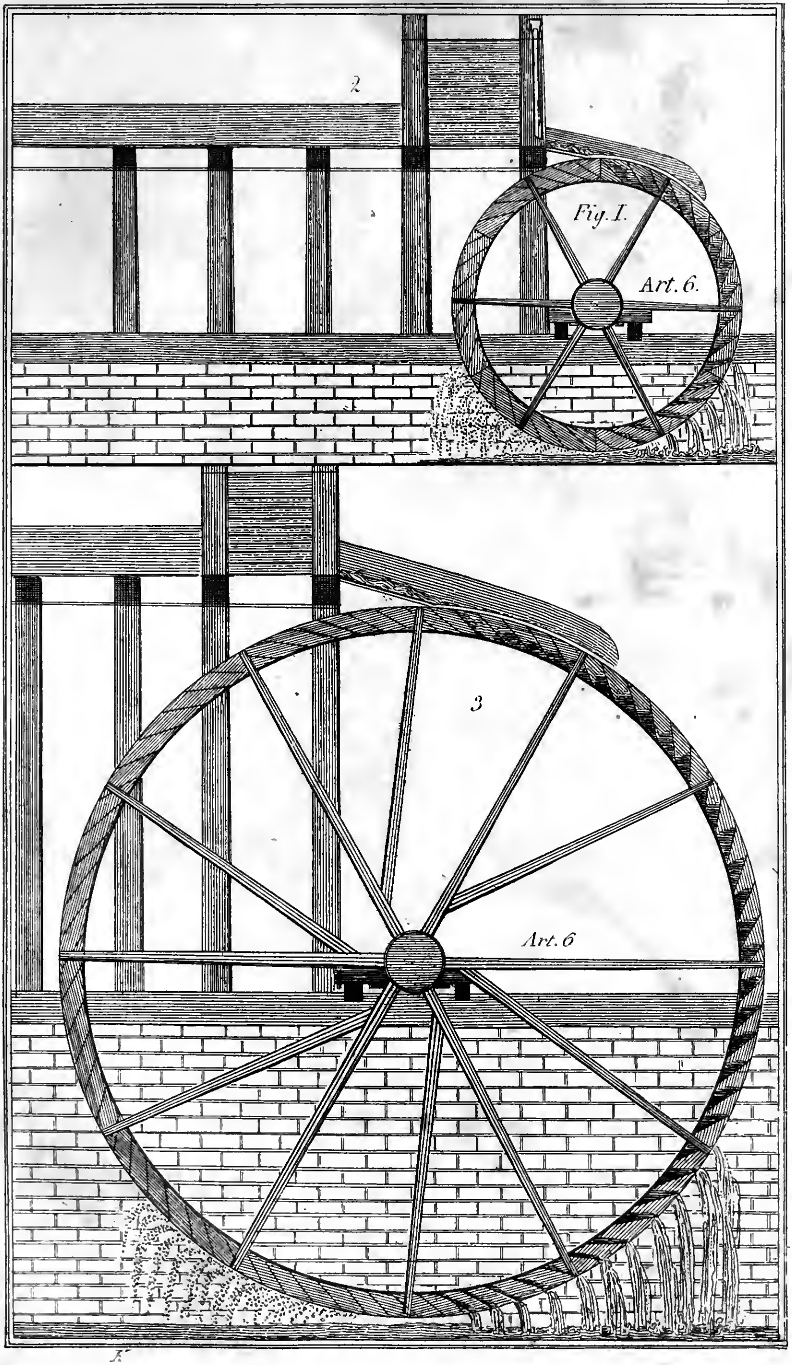
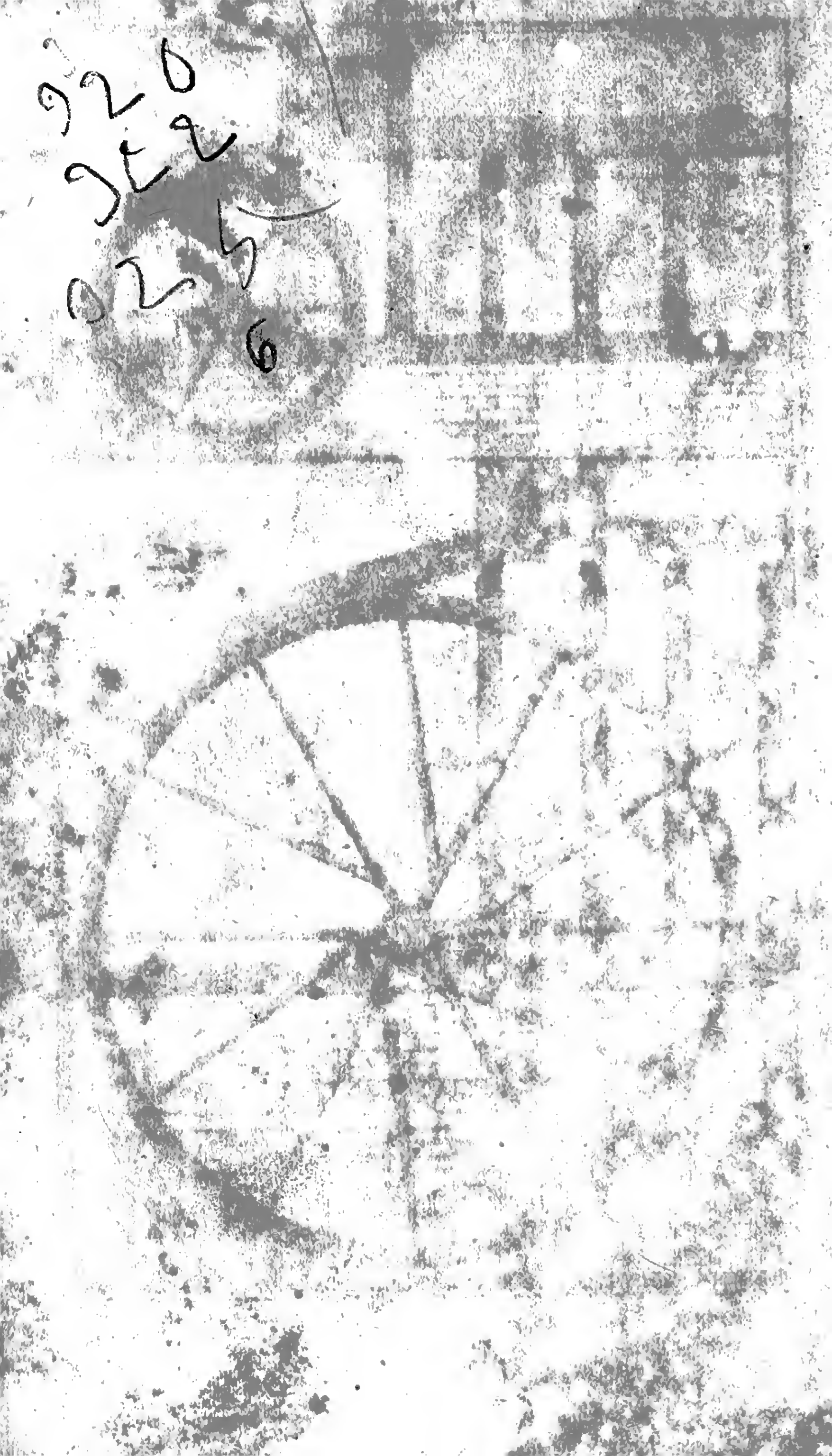
Art. 5.

Plate. XVI.





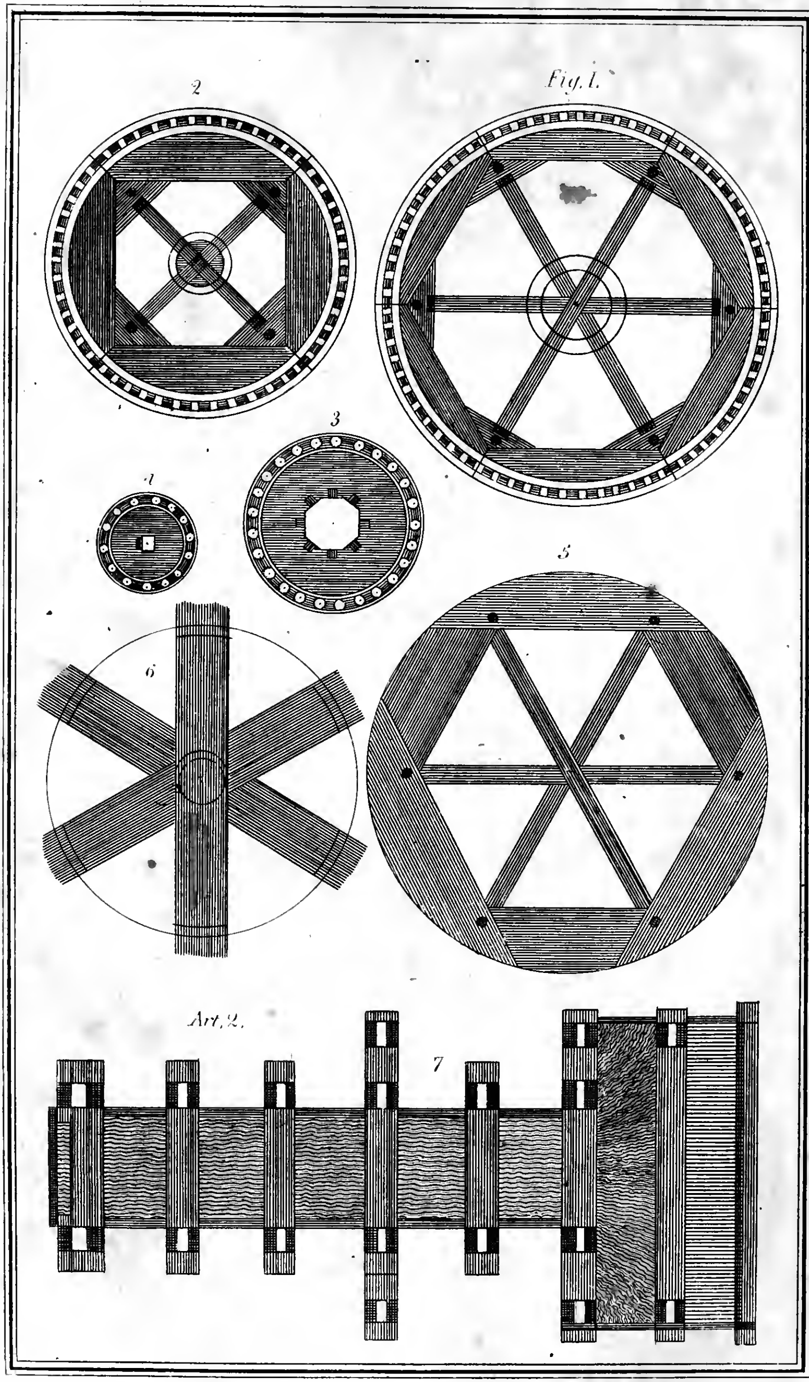


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Fig. I.
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Art. 2.
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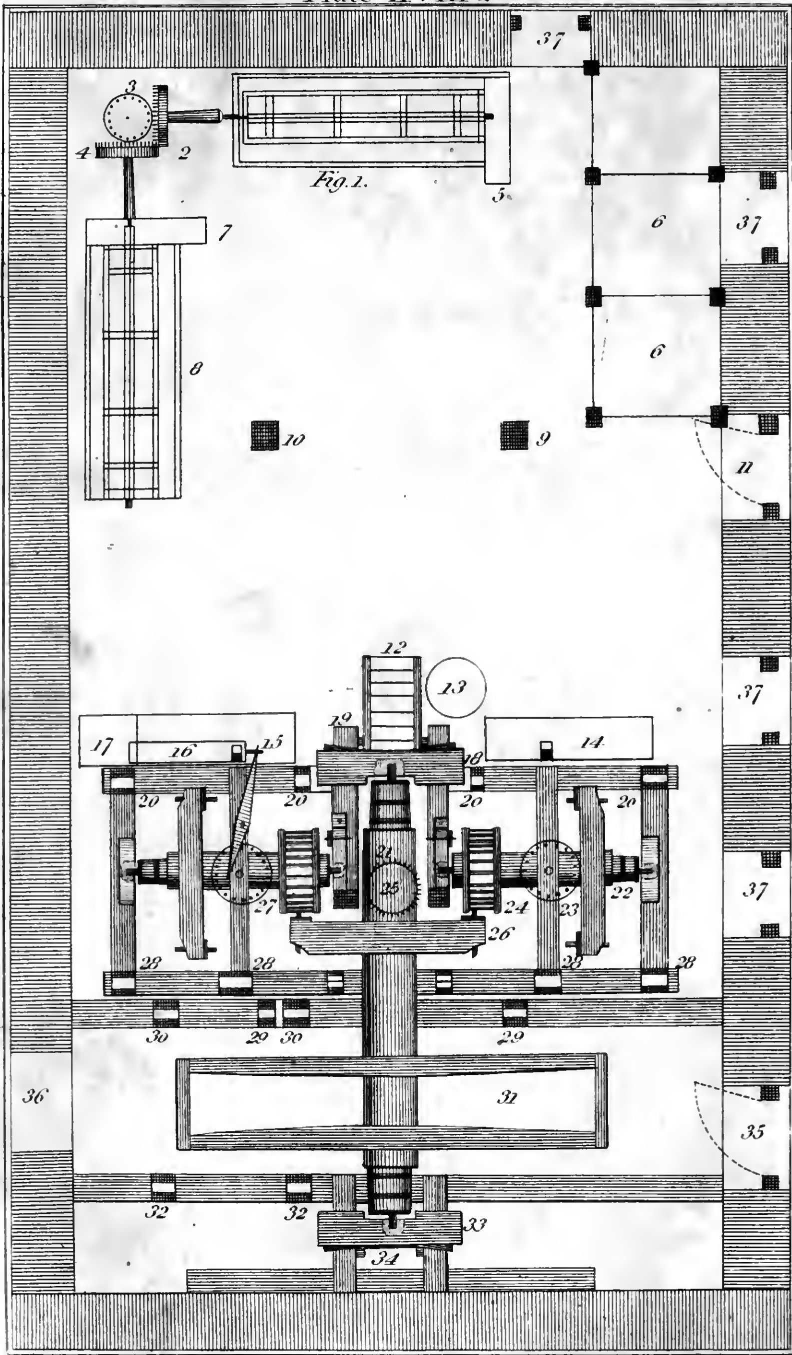
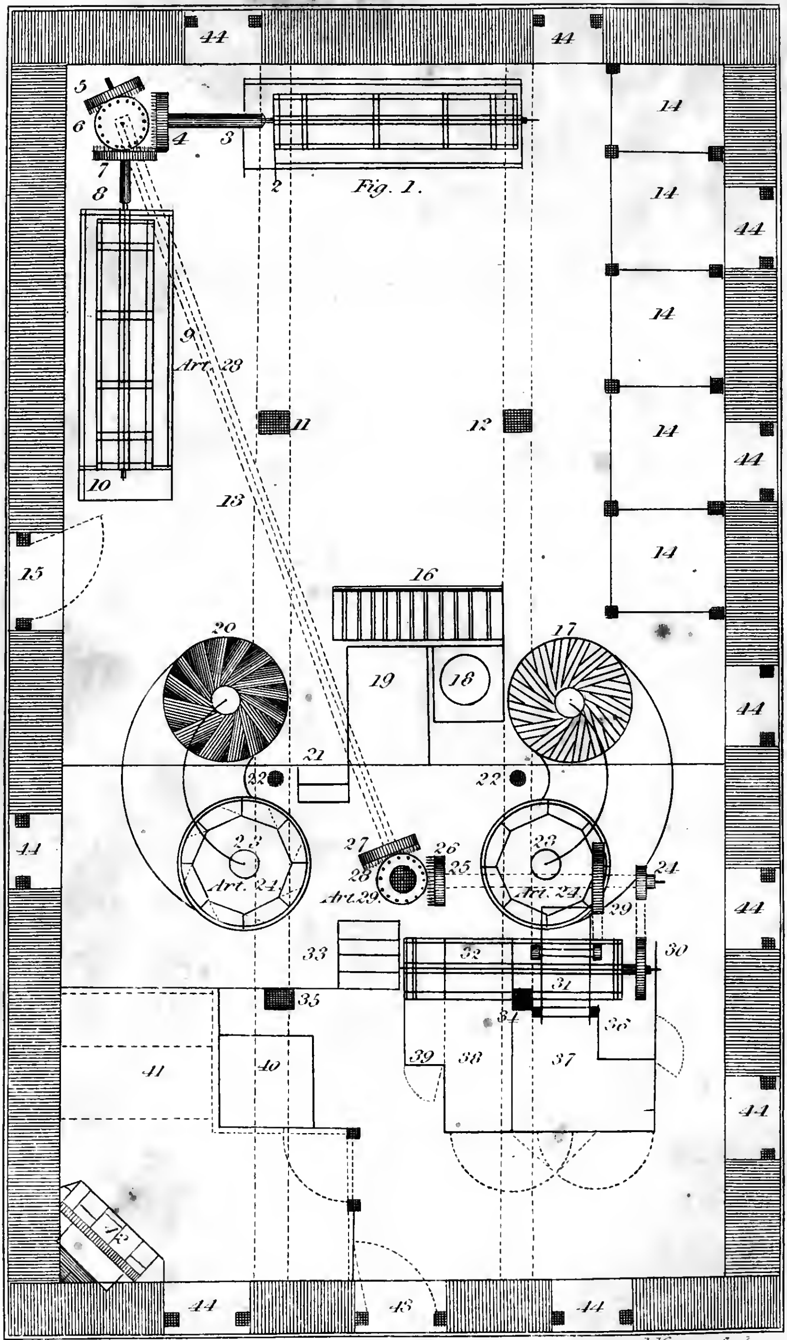
Plate XVIII..



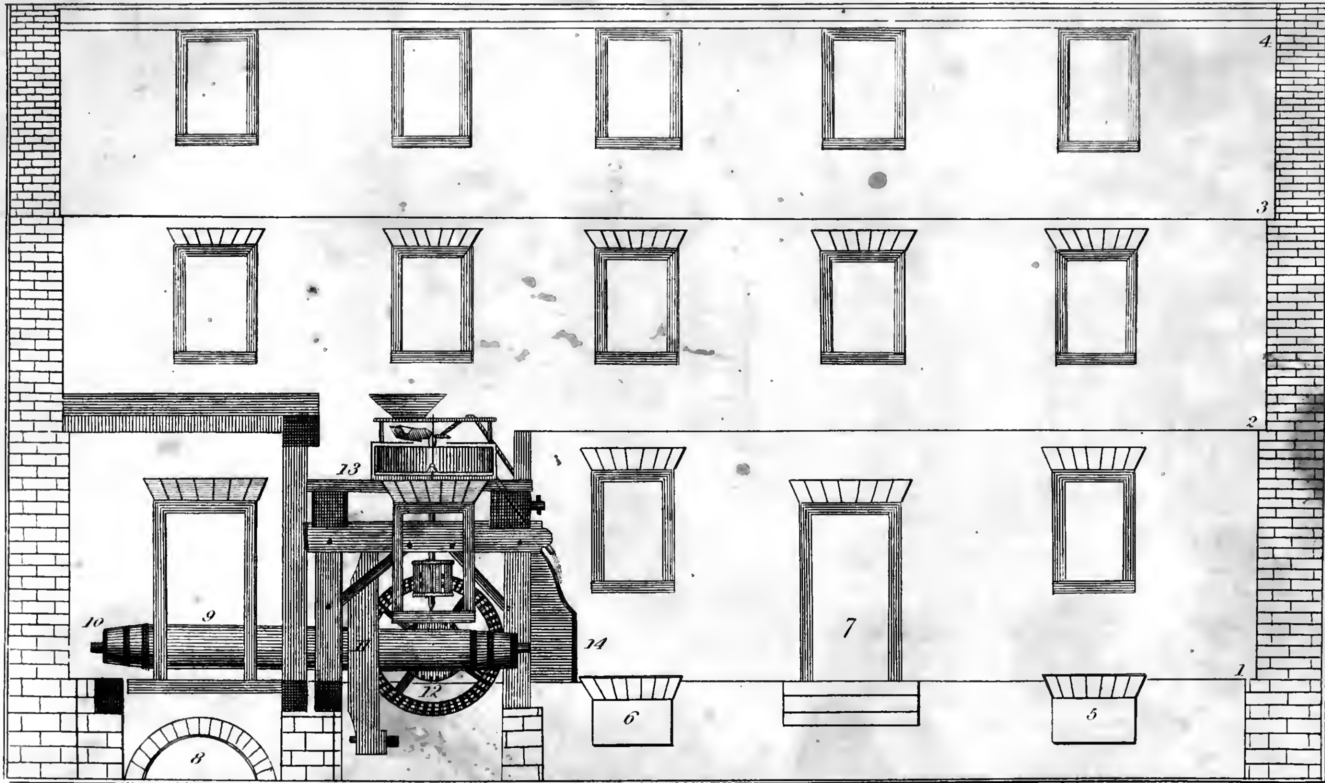
J. Kager Sc.

Plate . XIX .



J. Yeager Sculp.

Plate XX.



J. Yeager. Sculp.

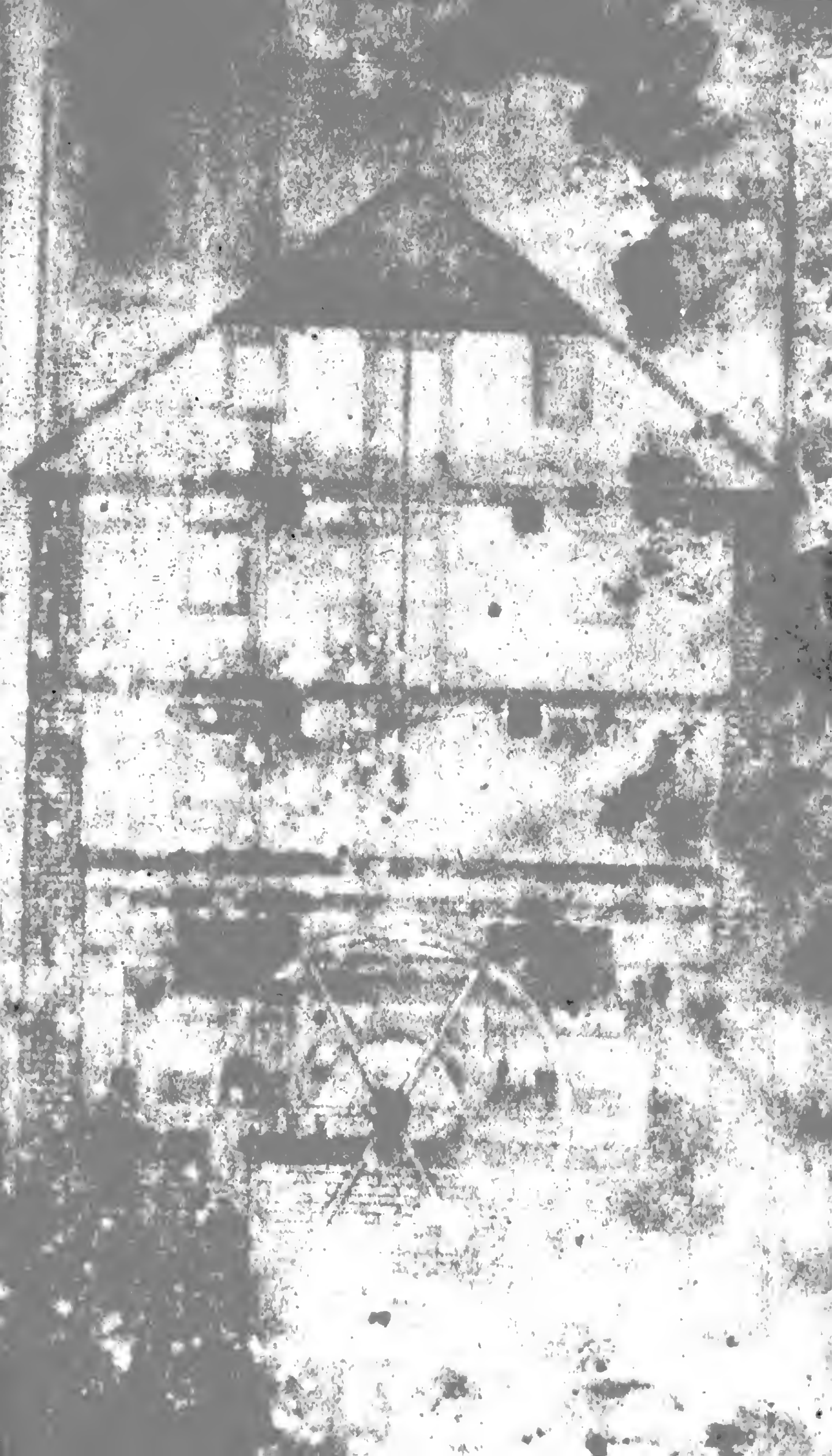


Plate XXI.

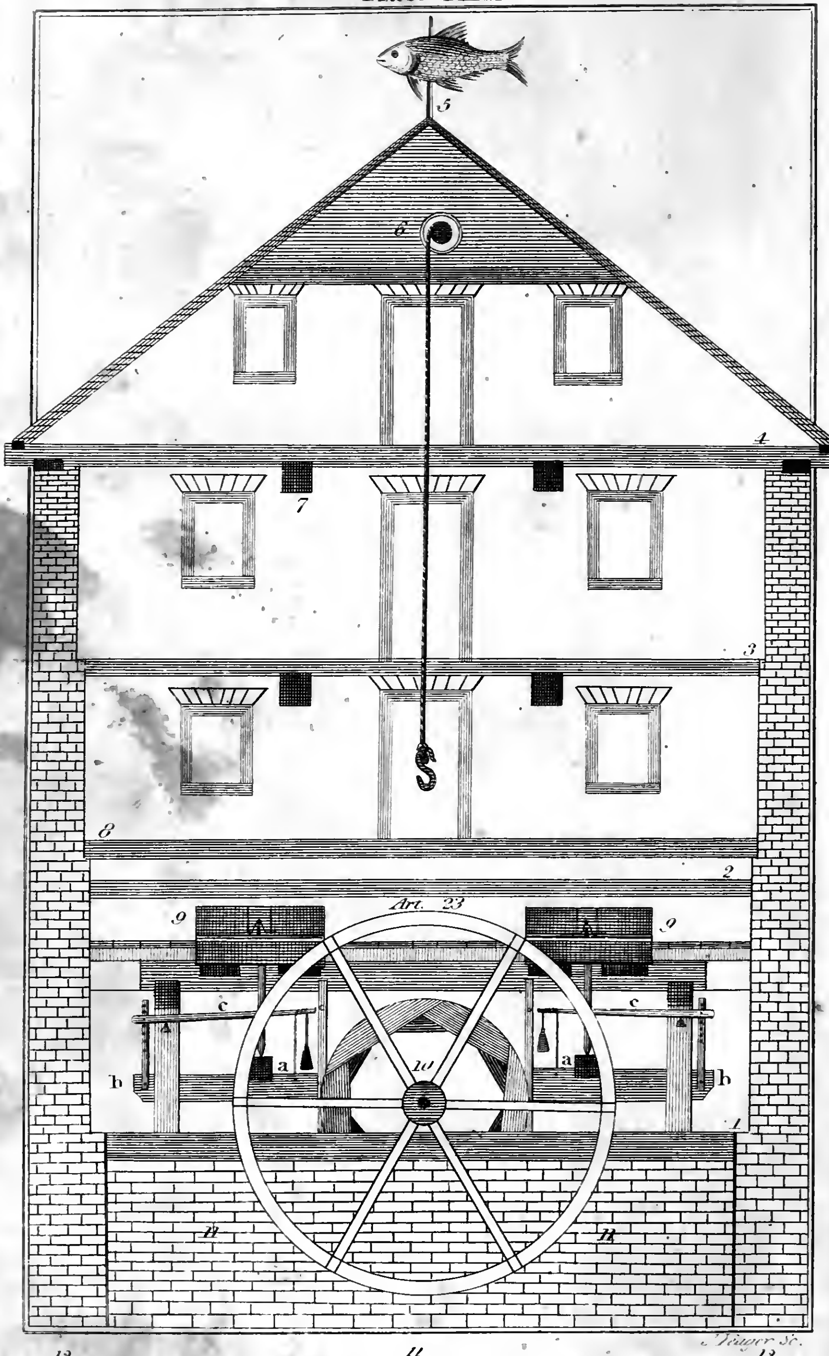


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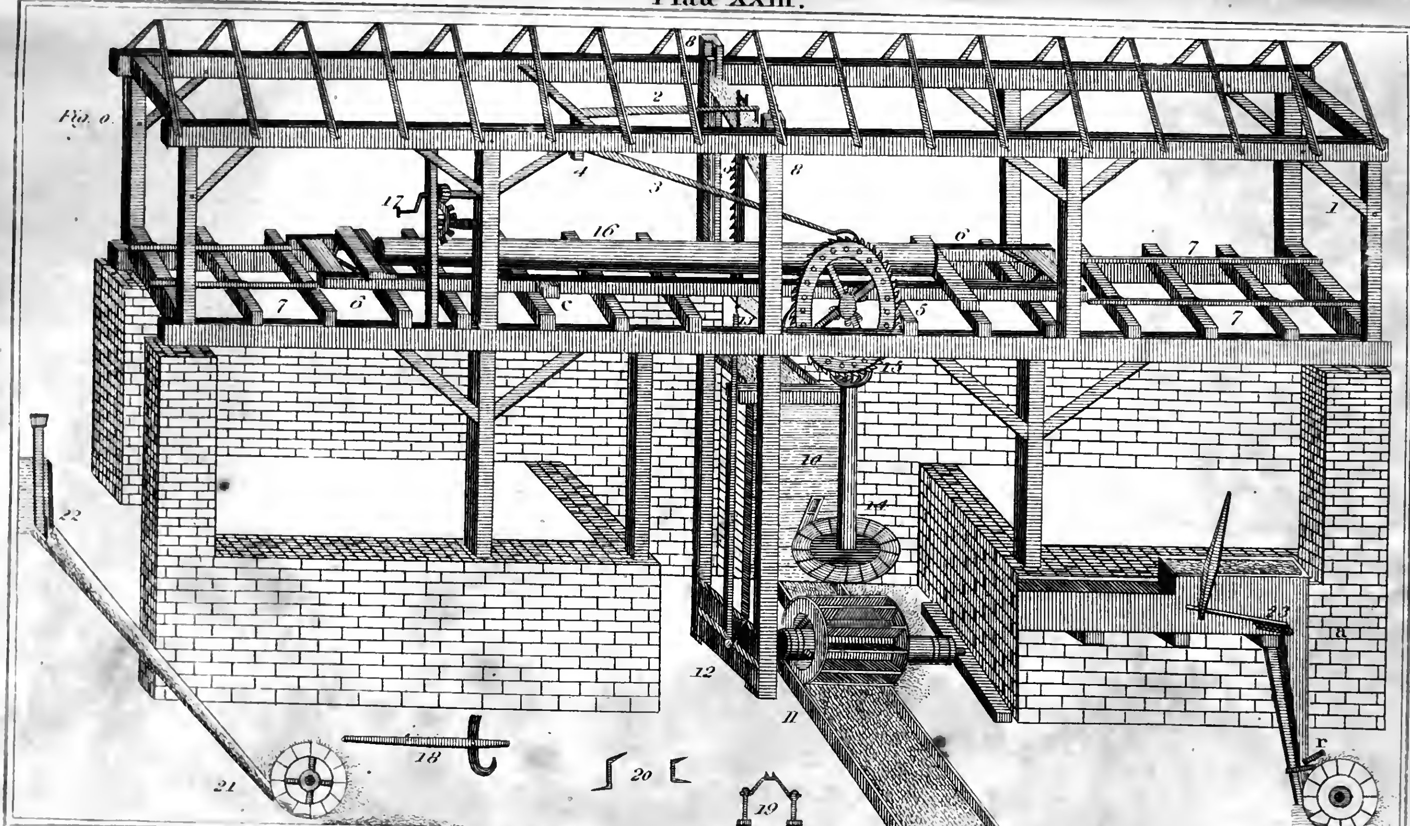
Plate XXIII.



J. Vager sc.

[illegible]

Plate XXIV.

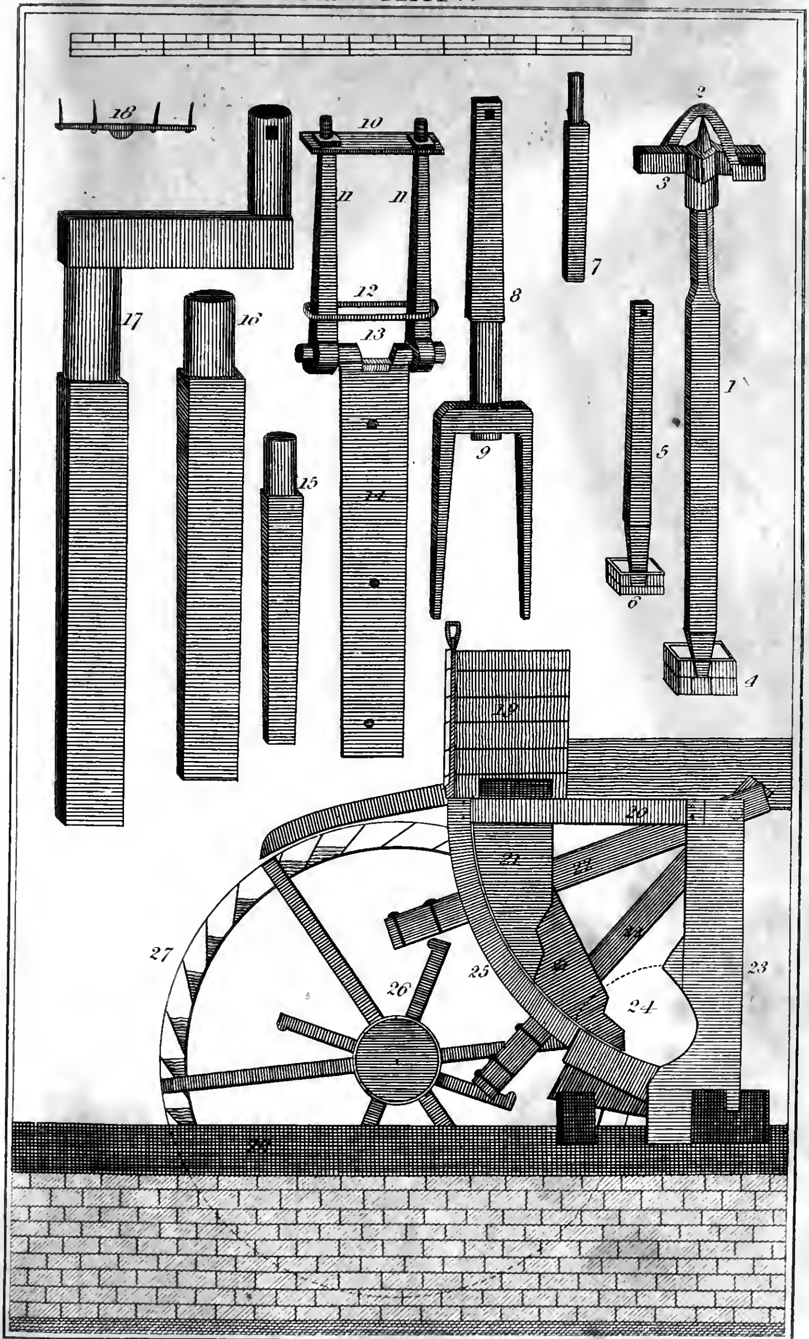
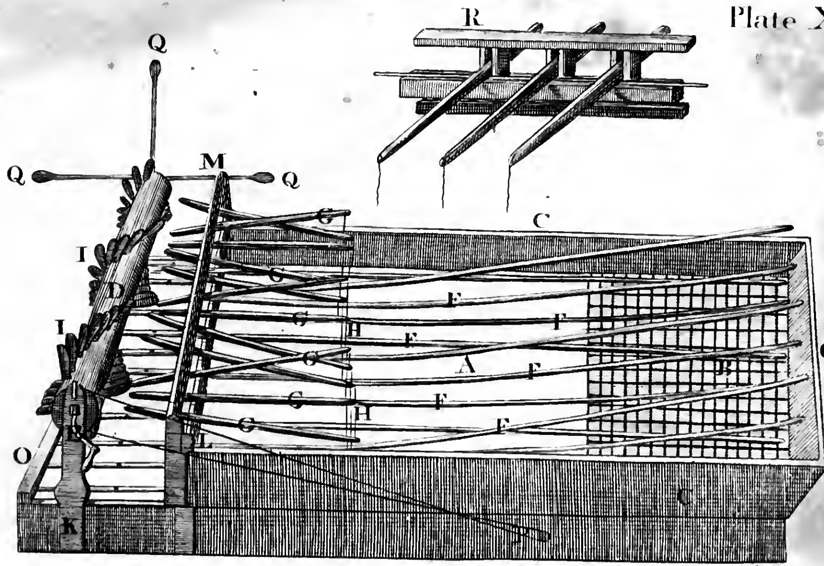


Plate XXV.



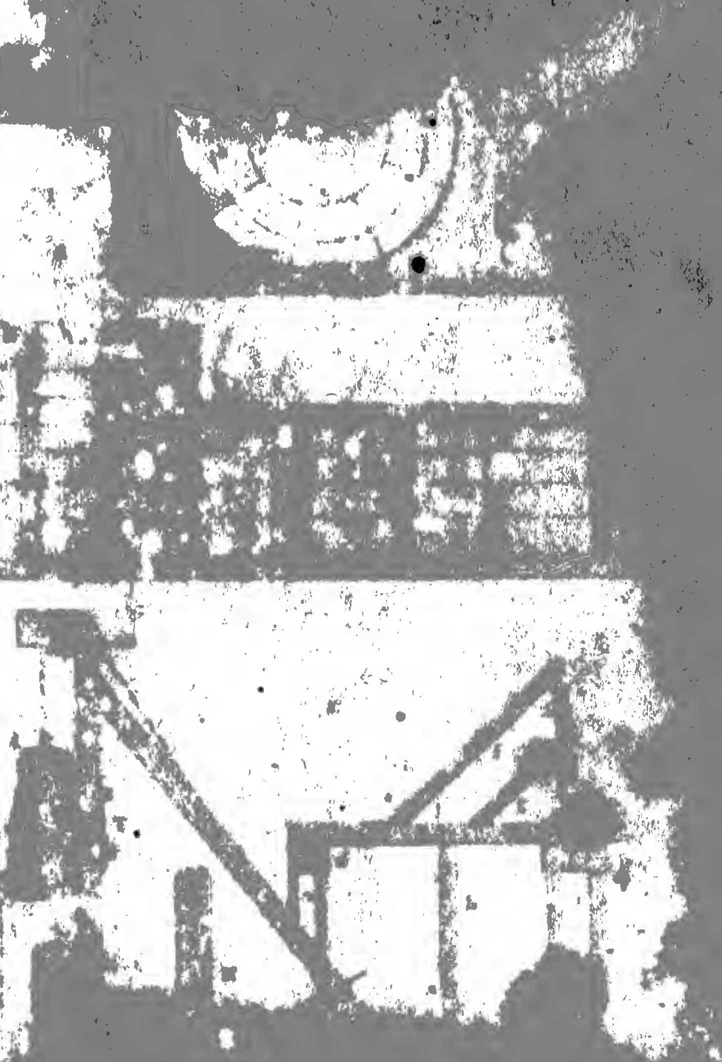
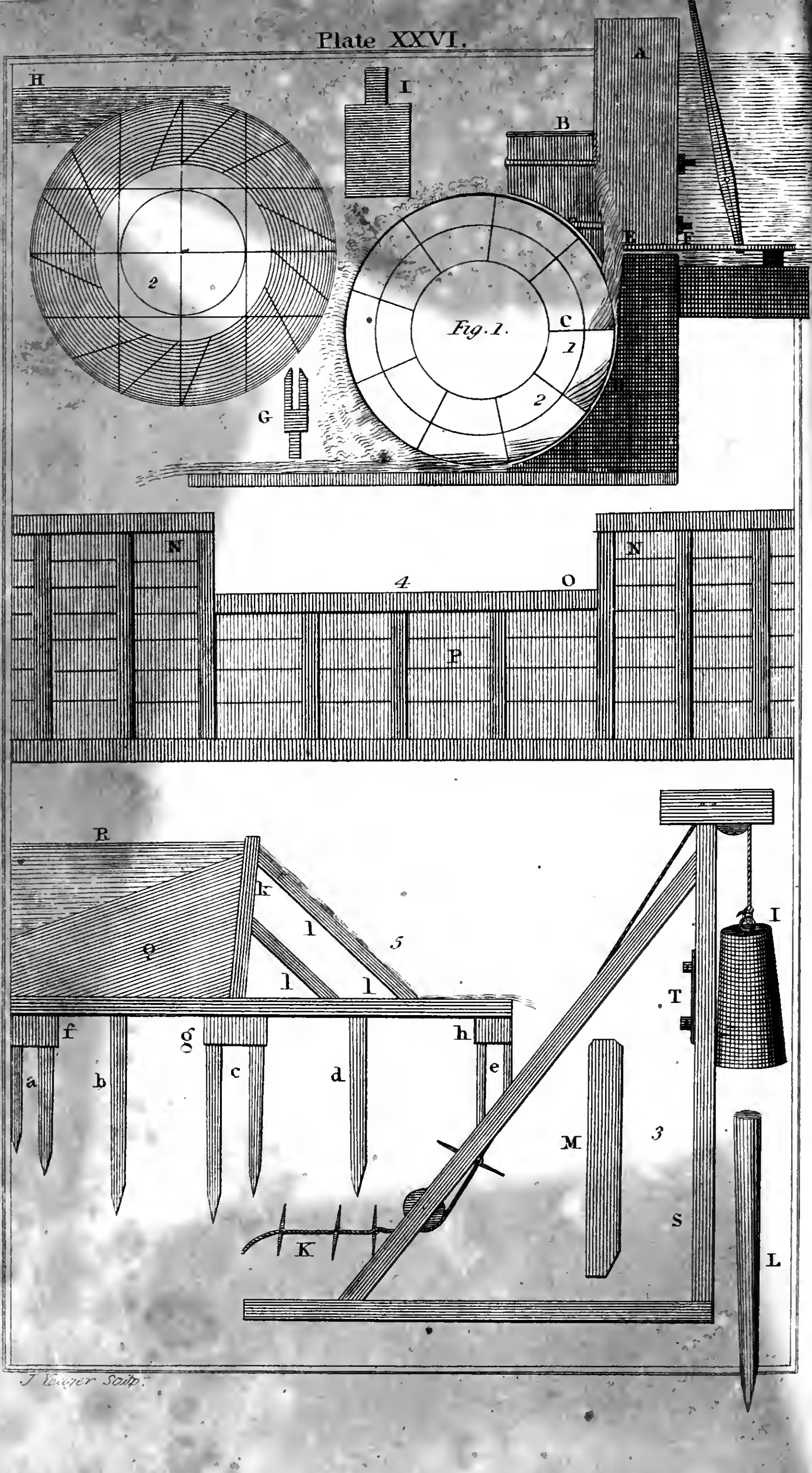


Plate XXVI.



J. Yeager Sculp.

Ellsworth Lewis